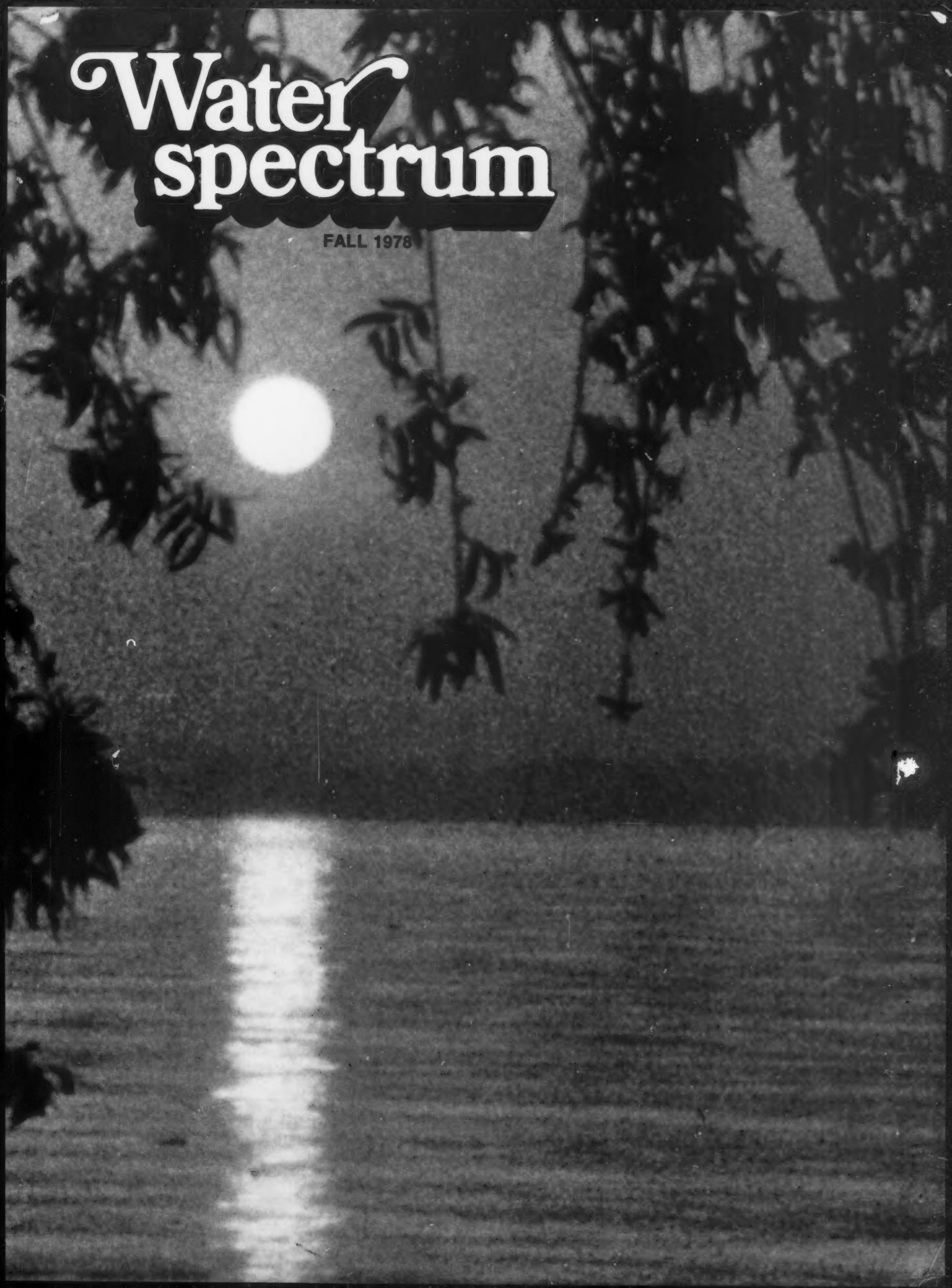
Water spectrum

FALL 1978



Water spectrum

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COVER: *"Water is the noblest of all the elements."*—Pindar

stream ecosystems

by **Kenneth W. Cummins and George L. Spengler**

Water quality of streams and rivers is often a problem of semantics. The most stringent definition is usually viewed as potability. However, a pristine trout stream and a chemically treated one may be equally suitable for human health needs, but totally different biologically. It is the maintenance of biological quality that carries with it many long-term benefits to humans—direct and indirect, and at little cost. Reclamation, on the other hand, can be expensive, or even impossible. It is important to ask what functions natural ecosystems perform, before alterations are made which require a long-term commitment of energy-consuming manipulations.

It is unlikely that humans, through accident or design, will produce altered systems that behave as efficiently as natural ones which represent the culmination of over 200 million years of evolution and at least 10,000 years of biological acclimatization. Much of the activity of the next decade will be spent attempting to undo environmental damage of the last century and, hopefully, implementing wise protection and management strategies for existing quality environments. Therefore, it seems timely to describe some of the fundamental features of the structure and functioning of running waters and to explore the implications of our present level of understanding in relation to management practices.

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Watersheds—The Fundamental Units

Drainage networks are dominated by small headwater streams which are inseparably dependent upon their watersheds—the land area drained by a given stream (Fig. 1). Therefore, the study of watersheds is basic to an understanding of the ecology of running waters and ultimately their protection, management, or reclamation. The characteristics of the watershed, for example

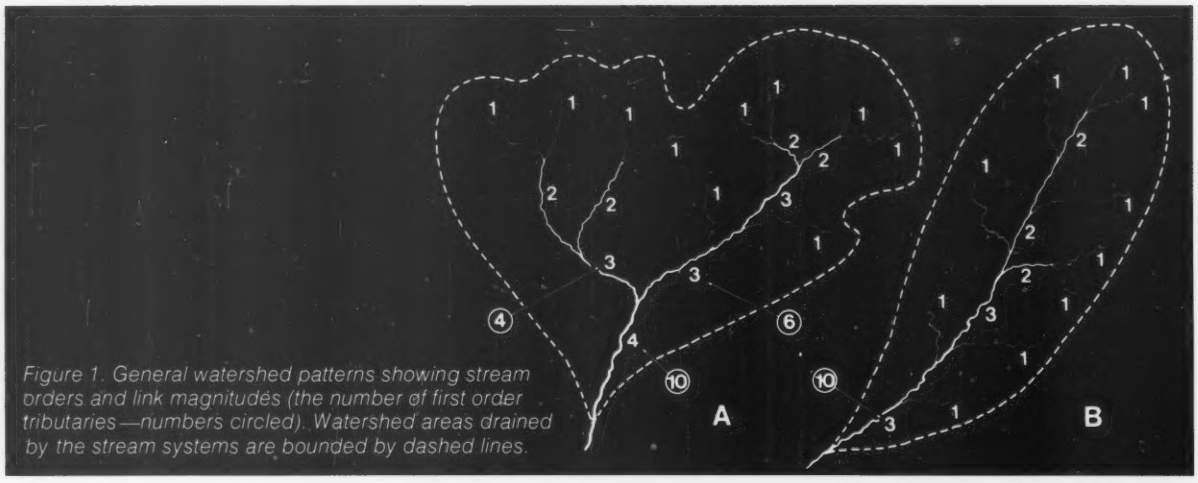


Figure 1. General watershed patterns showing stream orders and link magnitudes (the number of first order tributaries—numbers circled). Watershed areas drained by the stream systems are bounded by dashed lines.

vegetative cover, relief (gradient of the side slopes), aspect (compass orientation) and groundwater contribution, exert control over biological activity in the channel. Nature of the stream bottom sediments, amount of large wood debris (logs) and channel gradient are examples of in-stream modifiers of watershed influences.

In describing the relative size of a given stream channel and its position in a drainage network, stream scientists use a convenient "bookkeeping" method known as stream order (Fig. 1). Either the smallest, permanent headwater streams or smallest channels shown on a 1:24,000 scale topographic map are designated as order one. First order channels join to form second orders, seconds form thirds, etc. On this basis, the Mississippi River at its mouth is a twelfth order river. Over 85% of the 5.2 million kilometers (3¼ million miles) of streams and rivers in the contiguous United States are in first through third order tributaries. Almost half of all this distance is in first order streams, which average about 1.6 kilometers (one mile) in length. Link magnitude (Fig. 1), which describes the number of first order tributaries of a third order or larger system, is a useful expression of the degree of influence of the terrestrially dominated primary tributaries.

Streams may be conveniently viewed as *processors of natural organic matter* which for small, shaded, cool headwater streams (in the range of first to third order) is derived from the watershed. This is in contrast to the wide, shallow, warmer, well-lighted midsized rivers (approximately orders 4-6) in which green plants produce most of the organic matter through the conversion of solar energy to chemical energy by photosynthesis.

Photosynthetic production is supplemented by inputs from the extensive upstream headwater networks. Plant photosynthesis is limited by poor light penetration in the deep, turbid waters of larger rivers (order 7 and greater), which are primarily dependent upon inputs from the massive coalescing tributary networks.

Hydrology and Channel Morphology

The annual discharge regime, channel gradient and form, and the type of bottom sediments exert important influences on the biology of headwater streams. Although they are often incorrectly thought of as "stressful," annual floods are important reset mechanisms critical in maintaining normal community structure in streams. Periods of maximum discharge are usually in the spring and fall when algal growth in woodland streams is greatest because of maximum light penetration just before leaf out and just after leaf fall. The scouring effect insures that algal growth will not accumulate significantly—the probable result even at low light levels if flooding is prevented. More importantly, stored organic matter buried in the sediments, lying on the upper bank ("flood plain") or trapped deep in wood debris jams is redistributed at times of high water to more exposed habitats in the stream system where it is processed more efficiently.

The gradient and composition of the stream bed are important in determining the types of organisms and their distribution and abundance. Erosional areas (riffles) of turbulent, rapid flow are characterized by bedrock and/or coarse sediments such as cobbles and boulders. These well–oxygenated areas are inhabited by organisms having special adaptions for attachment or avoidance of the main thrust of the current. Depositional areas (pools) are regions where fine sediments accumulate and buried organic matter normally becomes anaerobic. Under such low oxygen conditions processing rates are very slow. Organisms inhabiting depositional habitats are adapted for moving through the upper level or over the surface of the fine sediments.

Ecology of the Headwaters

Because the ratio of shoreline to area of stream bottom is high in the headwaters, the influence of the riparian vegetation is maximized. The vegetation provides shade which limits plant growth (predominantly attached algae) and contributes the major organic inputs—leaves, needles, twigs, nuts, flowers, bud scales, etc. These dead plant parts are the dominant component of the detritus (dead organic matter and the associated microorganisms) which constitutes up to 90% of the organic matter which supports headwater stream communities. The remainder of the organic supply is derived from photosynthesis by such stream plants as diatoms (algae) and aquatic mosses.

The general aspects of headwater stream ecosystem structure and functional interrelationships can be visualized (Fig. 2) by partitioning the organic matter supply for the biological community into five categories: 1) coarse particles, generally greater than 1 mm in size[1], including such materials as leaf litter; 2) fine particles, generally less than 1 mm, such as leaf fragments and invertebrate feces; 3) solutions—dissolved organics less than about ½ micron in size[2]; 4) microscopic (e.g. algae), and; 5) macroscopic plants or producers (e.g. mosses). Particulate and dissolved organic matter are derived from the landscape and the fine particulate (FPOM) and dissolved (DOM) fractions are also generated internally: FPOM and DOM from coarse particles (CPOM) such as leaves, and FPOM from DOM. Most of these changes in particle size involve biological activity such as the invertebrate shredders which feed on leaves, producing fragments and feces.

[1]One millimeter = 0.039 inches
[2]One micron (= micrometer) = one tenthousandth of a millimeter

Processing of Leaf Litter

As an example of coarse particulate organic matter (CPOM) processing, the fate of basswood leaves is followed in the accompanying diagram (Fig. 3). Once a leaf has fallen directly, or has blown along the bank into the stream and becomes wetted, it begins to lose dissolved substances through leaching. This "tea-leaf" effect is largely complete within the first few days and represents significant amounts of dissolved substances, with some types of leaves losing 30 to 40% of their dryweight. Leaves entering a reach of headwater stream are generally entrained within about 100 meters (328 ft.) of their point of entry. As much as 60% of the particulate organic matter entering a given stream may be in the form of leaf litter.

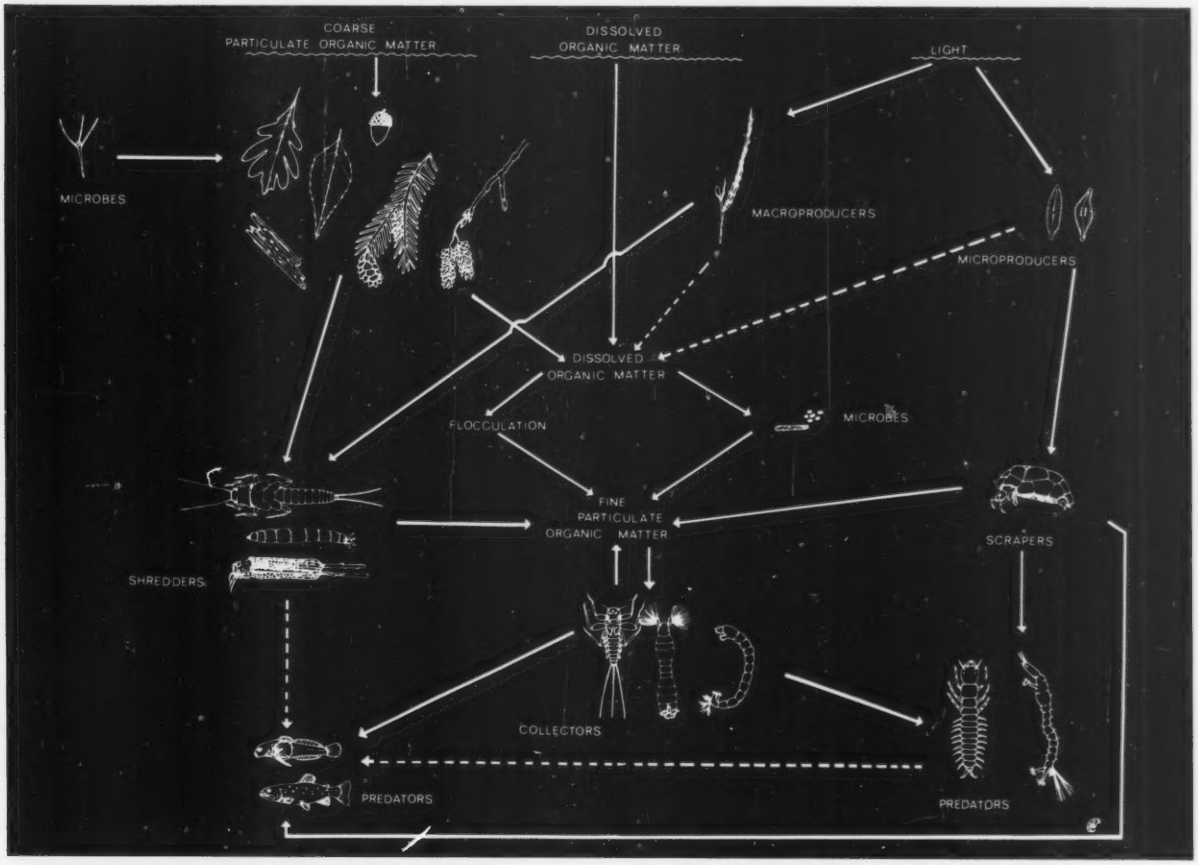


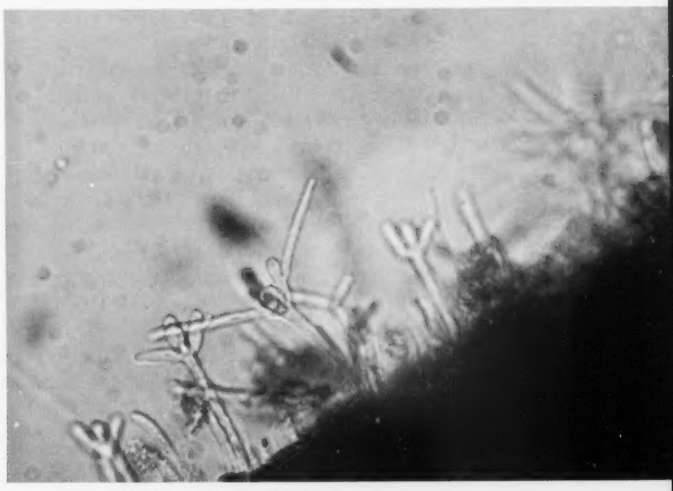
Figure 2. A generalized model of stream ecosystem structure showing interrelationships between functional components and emphasizing the processing of particulate (POM) and dissolved organic matter (DOM). POM is divided into coarse (CPOM) and fine (FPOM) particular organic matter or detritus. CPOM, exemplified by leaf litter, is colonized by microorganisms represented by an aquatic hyphomycete fungal spore and fed upon by shredders such as the stonefly nymph and cranefly and caddisfly larvae shown. FPOM is utilized by collectors such as mayfly nymphs and blackfly and midge larvae. Scrapers, such as certain caddisflies, harvest microscopic green plants like the diatoms shown. Mosses and other macroproducers are fed upon very little until they die and become part of the detritus. DOM is utilized by microorganisms such as the rod-shaped and spheroid bacteria depicted. Predators such as the fish (sculpin and trout) and invertebrates (dobsonfly and predaceous midge larvae) shown, feed on the other animal functional groups.

The leached leaves, which are relatively high in rather resistant carbon compounds such as cellulose and lignin and poor in nitrogen, are rapidly colonized by stream microorganisms—fungi and bacteria. An extremely important group is the aquatic hyphomycete fungi. They are very well adapted for cool headwater streams; most species can degrade cellulose and some can metabolize lignin. Hyphomycetes also have simple life cycles, enabling rapid colonization and growth, and can obtain their required nitrogen from the water.

The nutrition of the leaf litter-eating shredders is dependent upon the microorganisms which colonize the leaves. It is as if the microbes (fungi and bacteria) are protein-rich "peanut butter" which only occurs on nutritionally less suitable "crackers." In order to obtain "peanut butter," the "crackers" must be eaten. Shredders skeletonize leaves by feeding on the softer portions which contain the most microbes and also preferentially select those leaves which have the most "peanut butter." Leaf types which are colonized and utilized more rapidly by fungi and bacteria, and therefore fed upon first by shredders, are processed first. Such leaf types, for example basswood, ash, alder and some maples and hickories are termed "fast" in contrast to "slow" species such as aspen, oaks, beech, and many conifers.

Typical examples of shredders are the larvae of certain species of craneflies, caddisflies and midges, and the nymphs of a variety of stoneflies. Many of these are large invertebrates, up to 5 cm (2 inches) in length when fully

*One of the dominant shredders feeding upon leaf litter is the larva of the cranefly (*Tipula*). This animal will "select" and consume those leaves which have the greatest density of fungi and bacteria. The caddisfly larva (*Pycnopsyche*) and stonefly nymphs (*Pteronarcys*) are other typical shredders.*



Stream microorganisms rapidly colonize newly entrained leaves. It is this protein-rich "peanut butter" on a largely cellulose "cracker" that nutritionally supports the leaf-eating shredders. (Kellog Biological Station photos)

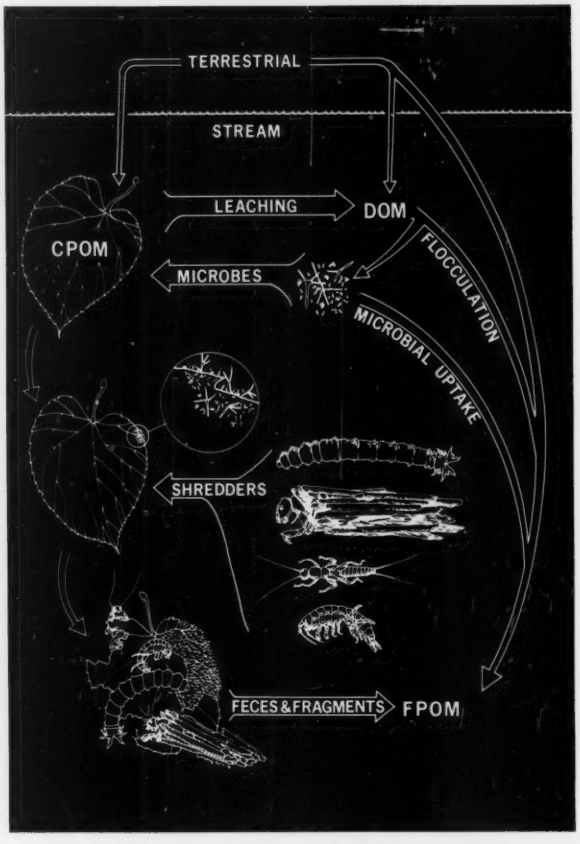


Figure 3. The processing of coarse particulate organic matter (CPOM) to dissolved organic matter (DOM) and fine particulate organic matter (FPOM). Emphasis is on the role of microorganisms (aquatic fungi and bacteria) and shredders such as the cranefly, caddisfly, stonefly and amphipod (scud) shown.

Autumnal leaf fall provides the largest input of particulate organic matter to the detrital processing stream community. Although the life cycles of most shredder and collector species are closely coordinated with this autumn input, slight asynchronisms from one species to another allow for the maximum use of all available resources.

grown, with powerful chewing mouth parts. Their life cycles usually are closely keyed to autumnal leaf shredding, with the eggs laid in fall and growth completed by late spring. Some shredders spend the early summer as inactive, non-feeding larvae until pupation in the late summer.

Studies conducted at the Kellogg Biological Station have utilized "leaf packs" to investigate leaf litter processing—that is, the combined action of microbial metabolism, shredder feeding and the relatively minor mechanical breakage. Leaf packs are used to simulate the accumulation of leaves in the stream against the upstream surface of obstructions such as branches, logs or rocks.

Stream obstructions, such as branches, logs, etc., aid in the retention and concentration of particulate organic matter, facilitating use rather than export.

Leaves are fastened loosely together in a pack and the pack attached to an elastic band. The band is slipped over a brick and placed in the stream with the pack facing into the current. The advantage for study of the prepared pack over natural leaf accumulations is that the initial time of entry of a measured amount of a given leaf type, or mixture of types, is known. A wide variety of observations is possible using these leaf pack analogues of natural leaf litter, ranging from highly qualitative observations of gross changes to detailed analyses of weight loss, biochemical and microbiological changes, and the increase in associated shredder weight.

Studies with leaf packs in natural streams and experimental channels have shown that temperature generally controls processing in a stream of a given order; that is, the rates are usually fastest during the season of warmest temperatures. However, from first to third order streams there is a decrease in processing rate despite the general trend of increased temperatures as the streams get larger. The nearer the headwaters, the faster the processing rate, reflecting the importance of shredders and aquatic hyphomycete fungi in such small headwater streams.

Fine Particulate Detritus

The fine particulate organic matter (FPOM) generated from shredder feeding, aggregation of dissolved substances and direct uptake by microorganisms, and derived directly from the watershed, is fed upon by collectors (Fig. 4). Collectors feed on FPOM either by filtering the particles from the passing water or by gathering it from the bottom sediments, some actually ingesting their way through the sediments as they burrow. The fine particles are too small to normally support fungi, but bacteria colonize their surfaces. Again, the microorganisms serve as the "peanut butter," in this case a coating on a "cracker" fragment which itself contains little of nutritional value for the animals. Unlike the shredders, collectors feed according to particle size rather than the density of the associated microbes. For example, blackflies will readily filter aluminum particles in the appropriate size range.

The supply of FPOM in the water and sediments is dependent on the amount of processing as well as

Experimental "leaf packs," constructed and placed in the stream to emulate material accumulations, have proven to be extremely useful in examining leaf litter processing rates and the associated biological dynamics.

contributions from the watershed and tributaries. Periodic inventories of both fine and coarse detritus in transport and on the bottom are important sources of information on the overall processing of organic matter by the stream community. This processing is reflected in the ratio of CPOM to FPOM, which is always less than one and decreases with increasing stream order.

Photosynthesis

Even though the photosynthetic production of organic matter in a headwater stream by algae and mosses may represent 10% or less of the total annual amount utilized by the stream community, a few invertebrates adapted for scraping attached plant life from surfaces are always present. In the headwaters, photosynthesis increases with increasing stream order, and so do populations of plant-feeding scrapers.

Although nitrogen (N) and phosphorus (P) containing nutrients are stimulatory to photosynthesis, the severe light limitation in heavily shaded streams limits responses to increased levels of such substances. The N and P in dissolved organic compounds have their primary stimulator effect on the growth of microorganisms such as fungi and bacteria.

Predation

Predators, both vertebrates, such as fish, and invertebrates, capture prey which consist of shredders, collectors, scrapers, and other predators. Such animal-feeding species are part of the control system (along with parasites, bacterial and viral disease and mechanically induced death) which normally insures that no one population of organisms will become super-abundant at the expense of the others or the efficient operation of the ecosystem as a whole. A great deal of interest in headwater streams centers on their fish populations. The headwaters may serve as spawning sites for fish migrating upstream and as important sport fisheries for salmon, trout and bass. Usually the resident fish population of interest constitutes less than one tenth of 1% of the biomass in a headwater stream ecosystem. It is no wonder that attempts at managing such a tiny fraction of the total are often of only limited or short-term success.

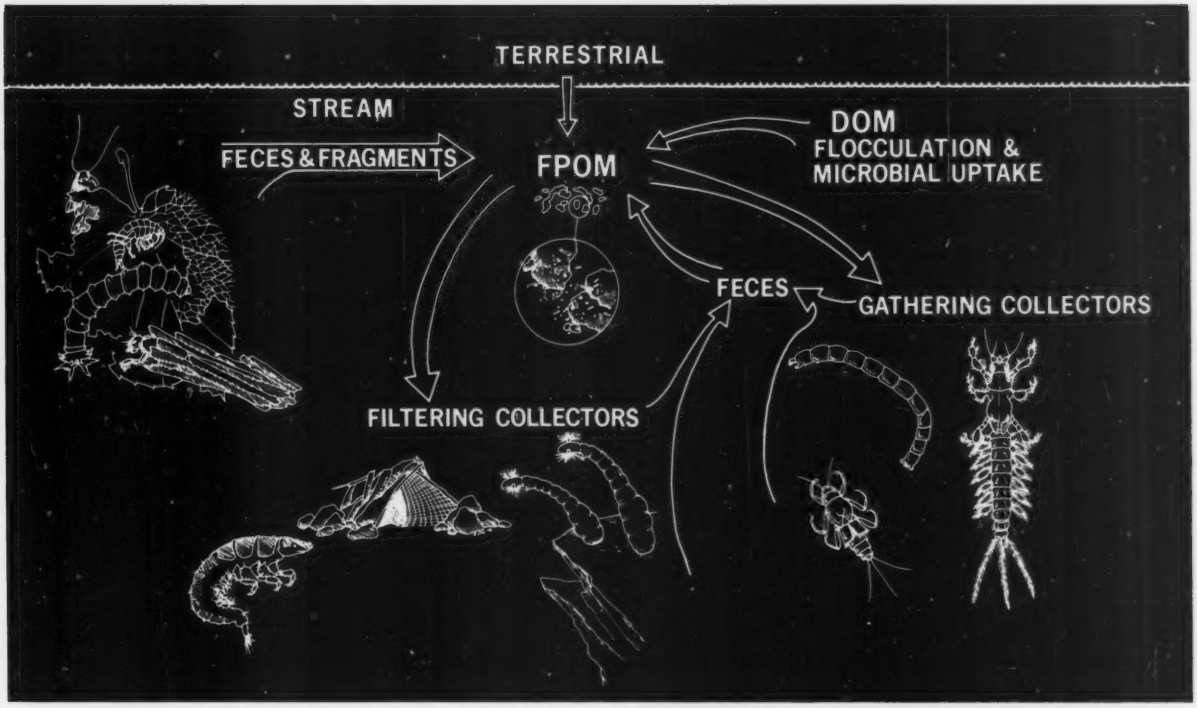


Figure 4. Use of fine particulate organic matter (FPOM) by microorganisms (bacteria) and collectors. Filtering collectors, such as net spinning caddisflies and blackflies, remove particles from passing water. Gathering collectors, such as midges, sprawling and burrowing mayflies, feed on fine particles in the sediment.

Experimental stream channels at the Kellogg Biological Station have been used to study the processing of natural organic matter. Experiments have included the manipulation of a) the quantity and quality of organic matter, b) density of shredder and collector populations, c) temperature, d) nitrogen enrichments, and e) various combinations.

be lost and the amount and nature of the material exported to the next stream order drastically altered. The availability of fish for harvesting from a given stream order is quite dependent upon this balance between processing and export.

Alterations of channel structure, for example more or less woody debris such as logs, can have dramatic effects on the physical retention characteristics of a stream reach. Such structures facilitate the accumulation of detritus, especially CPOM, and, therefore, become sites of intense biological activity. The addition or removal of various amounts of these retention structures could be an effective

Periodic measurement of the quantity and quality of CPOM and FPOM and the distribution of particle sizes within these two categories enables assessment not only of the potential food sources for the consuming community, but also the effectiveness of that community in processing the natural organics.

Protection, Management and Reclamation

Based on an understanding of how headwater streams have evolved to function efficiently in the processing of natural organic matter, it should be possible to accurately predict the effects of particular man-related alterations and to design more suitable management strategies.

Protection is largely a matter of preserving critical portions of the watershed. It is essential for normal stream function that at least a corridor (green belt) of natural vegetation be maintained along the stream course. This insures reduced light, cooler summer water temperatures and natural inputs of particulate detritus.

Because different types of organic matter are processed at different rates, for example "fast" and "slow" leaf types, selective harvesting or planting to alter the structure of the riparian vegetation community could have significant effects on the rates of biological activity in the stream. This could be an important management tool which has yet to be employed. Examples would be decreasing processing rates to offset temperature increases resulting from warming of the water, for example as the result of streamside ponding or irrigation return flow, or increasing processing rates to compensate for the unnatural loading of more resistant organic matter, such as that associated with the wood products industry. If we choose commercial expedience over the highly evolved and acclimatized natural biological communities, the efficient processing of the organic matter by one stream order can

*Several types of caddisfly larvae (*Hydropsyche, *etc.) construct nets to collect FPOM from the passing water. Fine particles thus captured are consumed.*

Fish population surveys, along with estimates of the quantity and quality of the natural organic load and estimates of the stream's invertebrate densities, are necessary for prudent management decisions.

Scrapers like the tortoise-shell, stone case caddisfly larva (Glossosomatidae) feed on attached algae such as diatoms which they remove from rock and log surfaces, leaving "grazing trails" such as these. (Courtesy N. H. Anderson, Oregon State University.)

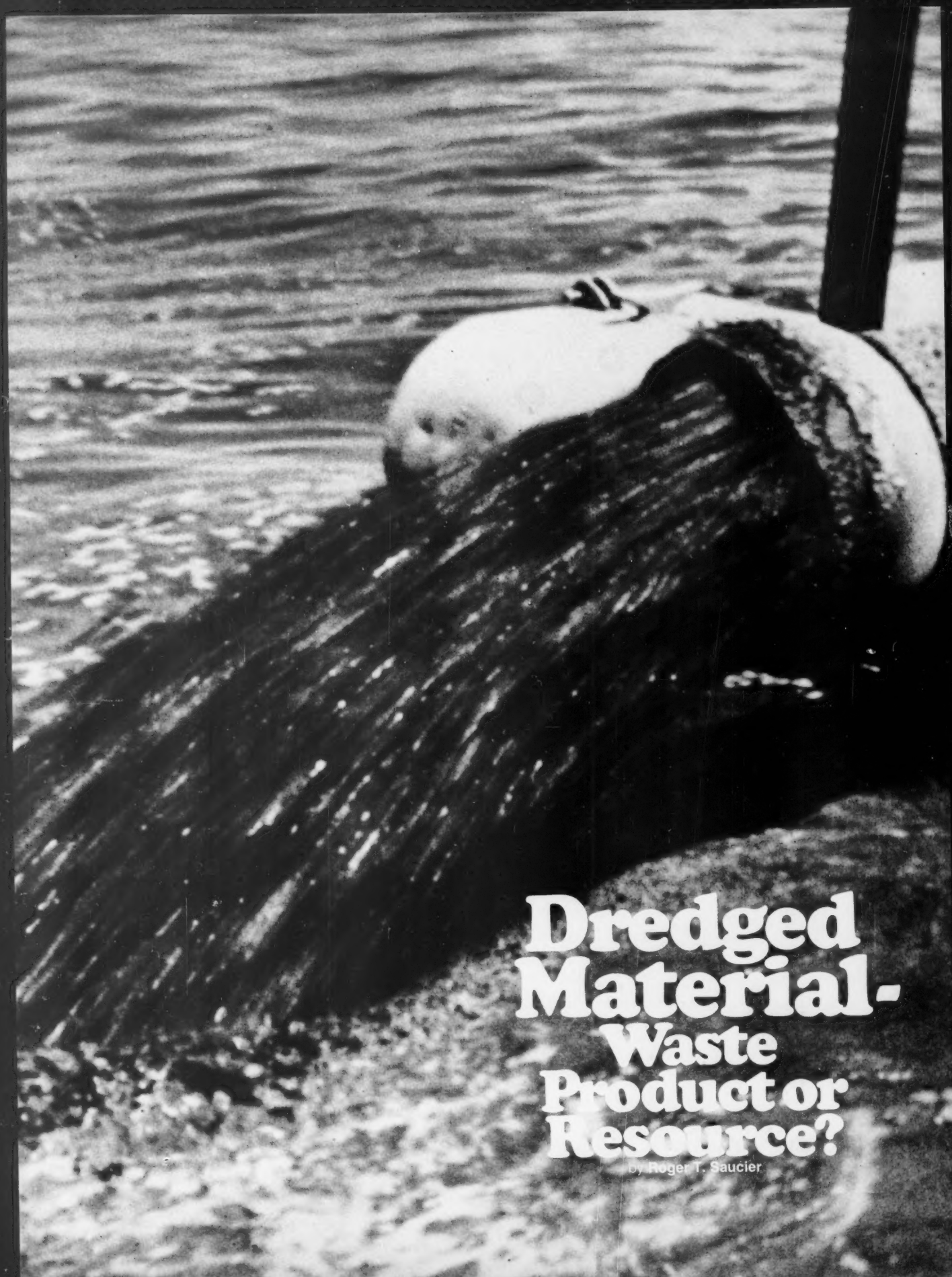
way of influencing the amount of processing in a reach of a given stream order and in the receiving stream order.

Impoundments in the headwaters which alter the normal flood cycle will, in the long term at least, have a dramatic effect on a stream system. In general, "flood control" is not in the best interests of long-term maintenance of natural headwater stream communities, and to some extent represents a failure to realize that the flood plains "belong" to the stream and not to man. If impoundments are constructed for irrigation or low flow augmentation, they should be off channel, and pulsed releases at times of normal flooding should be seriously considered.

Reclamation of streams which have failed to function normally will undoubtedly be difficult, in some cases impossible, within a given set of economic constraints. However, the basic functioning units of headwater streams have been identified. Thus reclamation becomes a matter of restoration of the riparian zone, establishment of the appropriate retention characteristics and enhancement of key groups of organisms playing vital functional roles in organic matter processing.

An important tool to be used in designing suitable strategies for protection, management and reclamation of headwater stream systems is computer simulation modeling. Interdisciplinary teams at Michigan State and Oregon State Universities, as well as other institutions, have utilized such mathematical models to investigate the effects of a large number of possible changes using high speed computers rather than natural streams. At the very least, such techniques aid in identifying critical problems to be investigated using real stream systems. It must be remembered, however, that such simulation studies have only been possible because an extensive data base exists on a few representative streams. Also, even if simulation techniques are employed, continued monitoring of biological parameters in natural streams will be required.

Certainly our best hope in stream management is a combined effort involving protection of critical watershed areas and channel structure, maintenance of appropriate organic inputs and associated organisms and continued testing of the effects of alternate practices using computer simulation techniques. ■



Dredged Material- Waste Product or Resource?

By Roger T. Saucier

Dredging the nation's waterways to improve navigation yields a troublesome by-product. Scooped or sucked from the bottom, this mixture of water and sand, silt, rock, debris and, sometimes, pollutants, goes by the name—for want of a better one—of dredged material. To develop and maintain navigation routes, the Corps of Engineers disposes of over 400 million cubic yards of dredged material annually, either in the water or on land. This is enough to cover Manhattan, the Bronx, and Staten Island more than three feet deep. Other dredgers move a similar quantity each year to create port facilities, build islands, mine minerals, construct airports, and accomplish other purposes.

Moving all that dredged material raises an inevitable question—what are the environmental impacts, good and bad, of dredged material disposal? Despite the importance of the question and the emotions that dredged material disposal often arouses, until recently little was known. Now a five-year, $32.8 million research effort, the Dredged Materials Research Program (DMRP) conducted by the Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi, has produced some badly needed answers.

The DMRP sought answers to the questions of why—and under what circumstances—does the disposal of dredged material produce adverse environmental impacts. It produced knowledge of the processes and mechanisms involved in environmental impacts, and most importantly, methods for predicting effects before a project is carried out or a dredge/fill permit granted. It resulted in methods for evaluating the relative impacts of alternatives for use by planners and design engineers. More significantly, it produced tested, viable, cost-effective methods and guidelines for reducing the impacts of convention disposal alternatives and removed much of the uncertainty and discredit surrounding new disposal alternatives and possibilities.

Attention was focused on keeping the DMRP as broadly applicable as possible on a national basis. No major type of dredging activity, region or environmental setting was excluded. While it may not be readily apparent, guidelines developed for confined disposal facilities and habitat development on disposal sites are as applicable in the Great Lakes area or the Mississippi Valley as they are on the West or East coasts. The fact that time and funds permitted field tests and/or demonstrations in only one or two locations should not be misleading.

An important finding of the DMRP was that there is no single disposal alternative that presumptively is suitable for a region or a group of projects. Correspondingly, there is no single disposal method that presumptively results in impacts of such nature that it can be categorically dismissed from consideration. Put in different terms, there is no inherent effect or characteristic of an alternative that rules it out of consideration from a technical standpoint prior to specific on-site evaluation. Each project must be considered on a case-by-case basis. Irrespective of pollution status or any other characteristic, it is not possible, for example, to make the general statements that ocean disposal must be phased out or that all material classified as polluted must be confined behind dikes. To do this would be contrary to the DMRP results that have indicated that there can be situations where there is greater probability of adverse environmental impacts from confined disposal than from open water disposal. Yet, in other situations—such as when certain types of contaminants are present—confined disposal may provide the greatest amount of environmental protection.

Case-by-case evaluations are time-consuming and expensive and may seriously complicate advanced planning and funding requests. Nevertheless, from a technical point of view, situations can be envisioned where tens of millions of dollars may have been or could be spent for alternatives that contribute to, rather than reduce, adverse environmental effects. It was also recognized, however, that technical considerations often are subordinate to policy, political, institutional, and/or legal ramifications. There can be no argument with this, but it is imperative for the decision maker to understand on what technical grounds, and with what technical trade-offs, decisions are being made.

Another observation is that environmental considerations probably are acting more strongly than any other force to necessitate long-range regional planning for a lasting, effective solution to disposal problems. No longer can disposal alternatives be planned independently for multiple projects in a given area for each dredging operation. While each project may require a different specific solution, the interrelationships must be evaluated from a holistic perspective and thought given to when particular disposal alternatives may have to be replaced with others as conditions change. Regional disposal management plans offer not only greater opportunities for environmental protection at ultimately reduced project cost, but also meet with greater public acceptance when they are agreed upon. As has already been pointed out, there are policy and institutional limitations affecting some aspects of regional management that need to be examined.

What, then, has the DMRP concluded, first with regard to the specific effects of open water disposal? With few exceptions, the physical effects—those logical and easily predicted physical effects—are more important than chemical or biological effects. By physical effects, it is meant the smothering of a clam bed, the disruption of a flow pattern, a change in salinity, or a similar effect. These possible consequences of disposal operations are persistent, often irreversible, and compounding. However, they are infrequent and can be avoided with the judicious application of evaluation procedures available under Sections 404 of the 1972 Federal Water Pollution Control Act and 103 of the 1972 Marine Protection, Research and Sanctuaries Act regulatory programs. More intense evaluations of physical impacts traditionally have relied on physical hydraulic models, but the DMRP has developed mathematical models that can also be used for certain needed predictions. Specifically, a partially verified and tested math model is now available to predict the short-term fate or dispersion of barge and hopper dredge

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The effect of turbidity or suspended sediment particles on aquatic life has long presented difficult problems.

dumped material as well as pipeline dredged material in ocean, estuarine, lacustrine and riverine environments. An unverified sediment transport model for the long-term and ultimate fate of these deposits will be available shortly.

Contrary to much public, scientific, and governmental opinion, the deep ocean, when analyzed in detailed, objective fashion, is not everywhere a fragile environment totally unacceptable for dredged material disposal. A significant DMRP contract study concluded that, should the economic and technological aspects be favorable, extensive deep ocean areas are environmentally more acceptable for disposal than are some highly productive continental shelf areas, especially for contaminated materials.

Turning to inland and coastal areas, the DMRP achieved results from theoretical, laboratory, and field investigations that show most fears about the short-term release of contaminants to the disposal site waters are unfounded. As long as the geochemical environment is not basically changed, which it could be with upland disposal, most contaminants are not released from the sediment particles to the water. Some nutrients, such as ammonium, and manganese and iron are released, but in most cases, enough mixing is present to rapidly dilute these to harmless concentrations. Situations where toxic effects could occur would most likely be where pipeline dredges are discharging large volumes of material into very shallow estuarine waters. The DMRP-developed model for predicting physical dispersion can also estimate the fate of conservative chemical constituents.

The effects of turbidity or suspended sediment particles on both water quality and aquatic organisms was one of the most difficult problems addressed by the DMRP. However, it was found that, except in unusually environmentally-sensitive areas such as coral reefs, turbidity is primarily a matter of aesthetic impact rather than biological impact. It is, of course, always advisable to schedule dredging and disposal operations to avoid disrupting spawning activities and fish migrations. However, the DMRP has shown that most adult organisms can tolerate turbidity levels and durations far in excess of what dredging and disposal operations produce. These studies have been conducted in the laboratory, verified in the field, and have involved a variety of marine, estuarine and freshwater organisms.

The resiliency of benthic or bottom dwelling organisms, once beyond the larval stage, has been demonstrated in the laboratory and the field. Disposal sites are rapidly recolonized by the establishment of new populations, migration of organisms from adjacent unaffected areas, and by survival of the organisms buried. Colonization by opportunistic species can occur within weeks and by the original species within months. When the type of dredged material disposed at a site is of the same grain-size distribution as the natural bottom (e.g., sand deposited on sand or silt), survival of existing organisms is maximized. Conversely, a mismatch of sediment type can be quite detrimental. The condition that could be most injurious to benthic organisms is when the disposal operations, primarily hydraulic pipeline operations, produce a fluid mud or "fluff" layer that is a difficult and alien environment for many organisms. Realization of the importance of this phenomenon came late in the DMRP and efforts have since been concentrated on understanding the mechanics of fluff formations, spread, and persistence.

It has been shown that certain aquatic animal organisms will ingest chemical contaminants, such as heavy metals, from dredged material. However, the ingestion patterns are unpredictably erratic and there are no clear trends. The complexity of this process and the low level of predictive capability have been controlling factors in the decisions that bioassays must be an integral part of the evaluative criteria used in implementing the Section 404 and 103 programs. It is fully realized that bioassay tests are expensive and time-consuming, but the state-of-the-art allows no effective alternative for determining how organisms will be effected by contaminated dredged material.

Determining the effects of open water disposal has been somewhat like trying to strengthen a chain. Once the weakest link is found and strengthened, attention is necessarily directed to the next weakest link. Major field studies at four open water disposal sites have strengthened several links. They verified several major laboratory findings and showed that short-term impacts are of short duration and are not of major environmental significance. These indeed can occur, but are certainly going to be the exception rather than the rule. In addition, the DMRP has called attention to situations where open water disposal has even had beneficial environmental effects and has identified operational procedures that can be used to reduce impacts without new technology or major cost increases.

All types of dredging activity, across all national regions and environmental settings, were considered in the DMRP.

The next weakest link in the strengthened chain involves long-term biological impacts. Certain selected field test sites will be monitored for three years beyond the end of the DMRP to provide some much needed information on this subject; however, many answers still will not be forthcoming. Among these will be ones relating to chronic or sub-lethal effects of very long term exposure of benthic organisms to contaminated material, and effects on reproduction.

Thus far, mention has been made primarily of assessing the effects of open water disposal and very little about controlling or mitigating these effects. The DMRP has not overlooked this aspect and even when an effect has been found to be an unlikely event, it was presumed there could be instances where control or regulation would be advisable for one reason or another. A good example is turbidity. Even where adverse biological effects are highly unlikely, there are reasons that excess turbidity should be

minimized. One study has called attention to how simple equipment maintenance and efficient operation can reduce turbidity and another has extensively evaluated and developed guidelines for using silt curtains for "diapers," pointing out when they can be effective and when they are nothing more than a placebo. Silt curtains are ineffective, for example, where currents exceed one knot and will be both ineffective and uncontrollable under moderate wave conditions.

Because of the peculiar nature of the problem of turbidity, a concept has been developed, but not yet field tested, for the submerged discharge of material from a hydraulic pipeline dredge through a specially designed underwater diffuser. Model tests of the diffuser show it has excellent potential for reducing turbidity as well as reducing the extent of the potentially harmful fluid mud layer that often develops.

DMRP studies considered the feasibility of treating contaminated dredged material to reduce the impact of disposal operations. Because of the large volumes and variable nature of the material involved and the very low concentrations of contaminants, most conventional treatment processes are infeasible, particularly when considered for use in the dredging operations itself. Some processes are feasible for confined disposal facilities and will be discussed shortly. However, with regard to open water disposal, only in-line oxygenation—to reduce the dissolved oxygen sag accompanying disposal of certain kinds of material being moved by a pipeline dredge—appears operationally and economically practical. The use of flocculents to reduce turbidity in an open water disposal situation is not effective or practical in most situations.

Marsh development has nearly universal potential.

The creation of insular habitat from dredged material is publicly acceptable due to the obvious environmental benefits.

Next to open water disposal, confined or diked containment of dredged material as a conventional alternative was the most extensively investigated under the DMRP. Confining contaminated material on land or in shallow water next to land can be an environmentally sound and preferred alternative, but not inherently better than open water disposal for several reasons. There are technical reasons why confined disposal could be less effective in protecting water quality for organisms. Also, it should not be overlooked that confined facilities are expensive, of finite life-span, and result in a permanent change in the physical landscape—often in conflict with land use and management plans.

Regardless of the alternative decision, if a confined disposal area is to be constructed, it must be designed, built, and operated in such a way as to achieve maximum effective capacity and satisfactory effluent quality. Unfortunately, neither of these basic objectives have been met by most facilities to date. These objectives are by no means mutually incompatible and the reasons they have not been met involve lack of technical knowledge as well as policy and institutional factors such as cost, funding sources, and diffuse construction and management responsibilities.

If a confined disposal site is to be effective from an environmental protection standpoint, it must be efficient in retaining a high percentage of the finer soil particles, for it is the clays and silts that carry the contaminants. These are admittedly the materials most difficult to retain in an area, but if they can be, the effluents should be essentially non-toxic except for occasional situations where nutrient levels and oxygen depletion may be excessive.

There are cases, however, where sites are simply incapable of providing adequate retention. Addressing these situations, DMRP studies found that coagulants and flocculents can be quite effective for effluent treatment, and treatment system design and operation guidelines are being developed based on actual field tests. Studies also considered the principles involved in the land treatment of wastewater and concluded from a limited field test that the regulated discharge of disposal area effluents through a natural marsh can be effective in removing nutrients.

With time, the soil physiochemical environment in a confined disposal site can become appreciably different from that of sediments before dredging or sediments deposited in open water. The upland, drained situation can lead to an oxidizing, acidic environment that has been shown in laboratory studies to be conducive to the leaching of contaminants, particularly heavy metals. Whether or not the leachate will contaminate groundwater will depend on the normally quite high absorptive capacity of the natural soil. A far more probable impact can occur when saline sediments are placed in a freshwater upland environment. Salt will leach from most dredged material and whether or not it will contaminate groundwater must be carefully evaluated on a case-by-case basis.

In terms of time, effort, and cost, the most expensive aspect of confined dredged material disposal can be the land acquisition. Moreover, since available land will continue to become scarce, the DMRP included studies aimed at alleviating or lessening this problem. These dealt with methods to increase the storage capacity of existing sites and/or concepts for making existing sites reusable.

Extensive field tests have proved that it is possible to dewater even some of the more difficult types of dredged material so that disposal sites can store more sediment and less water. A side benefit of this dewatering is improved engineering characteristics of the densified material. Through field investigations and tests, surface trenching proved to be cheap and effective in providing natural drainage. Whereas more complex and even exotic dewatering methods such as under-drainage systems and electroosmotic dewatering may be feasible where the cost can be justified, here is a case where the cheaper technique, relying heavily on nature, has been shown to be the most effective.

Bioassays will continue to be an integral part of dredging regulatory criteria.

areas and methods of disposal should a wetland area have to be used for disposal.

Considerable attention was given to the uptake of chemical contaminants by marsh plants as an obvious concern in decisions on developing marsh habitat using dredged material. Uptake has been found to occur in different ways and at different rates in most plant species, but the amount of contaminants involved have not been so large as to cause major concern. The question of how much is too much has not been resolved and is not likely to be anytime soon; however, evaluation should be made with an awareness of the natural functioning of a wetland system as a contaminant processor. The end product sought by the DMRP has been a test to predict the pattern in a particular type of material. To this end, it was largely, but not entirely successful, since the behavior of contaminants proved difficult to predict.

Dredged material may offer the ultimate answer to strip mine reclamation.

Dredged material also can be used to create or improve wildlife habitats—examples of this exist throughout the country. However, it is known that the past occurrences were primarily accidental rather than planned. Consequently, the DMRP concentrated on understanding the natural processes and developing guidelines on exactly what should be done, where and when, and what are the relevant considerations in all phases from site selection to followup management.

Certain basic studies concerned wetland plant productivity from two points of view. Knowing the relative productivity of species is one factor in selecting those suitable for planting at a habitat development project. It is also one factor in the extremely difficult problem of determining the value of a wetland being evaluated as a disposal site. Studies showed, for example, that the productivity of several so-called minor species is greater than anticipated and the ability of at least one species to recover from burial beneath dredged material up to 9″ thick is greater than expected. This information will be helpful in selecting

Thanks to the DMRP, marsh creation using dredged material is now a proved, viable method that can be designed and implemented as reliably as any other alternative. Also, certain misconceptions about this alternative can be firmly dispelled. In particular, it can be easily demonstrated that marsh development does not necessarily eventually preclude the disposal of material from subsequent maintenance dredging projects. There are examples where phased marsh development, with or without other disposal alternatives, has been planned in such a way as to accommodate maintenance dredging for periods of 50 years or more.

While marsh development is a field tested and proved alternative, it is not a simple one and it is not cheap. However, it is definitely cost-competitive with other alternatives and cheaper than some. Marsh development is not unusually difficult from an engineering point of view; no new equipment or technology is needed, but rather the dredgers are required to perform unfamiliar operations according to unusual time and accuracy specifications.

As indicated above, marsh development is not a satisfactory alternative for all locations, but there is no major geographical region where it is not desirable and possible. In other words, marshes can be developed in the Great Lakes area and along inland river systems as well in all coastal areas. The only known environmental conditions where it is probably not practical are ones with high tidal ranges and strong waves and/or currents. Otherwise, depending on local conditions, marshes can be developed in a variety of shapes and sizes, with different types of dredged material, with different plant species and planting techniques, and with or without retaining dikes.

In some respects, upland habitat development, either on new disposal sites or on reclaimed older sites, is a technology more advanced and more tested than marsh habitat development. Upland habitat includes food and cover for mammals, and nesting, resting or feeding areas for waterfowl. Most of these require only the application of existing agronomic and wildlife management practices. Upland habitat development can be relatively inexpensive and easy, and there are hundreds of disposal sites that could be improved environmentally and thus meet with greater public acceptance.

Small islands created by dredged material disposal in inland waterways and coastal bays and estuaries are a special type of upland habitat development. Several regional surveys sponsored by the DMRP showed more than 2,000 such Corps-built islands. In fact, a majority of the total U.S. population of such colonial nesting birds as sea gulls, terns, and herons are dependent upon islands of this type for their survival.

Thus, island development obviously can be an environmentally beneficial disposal alternative and one that has large public acceptance. Islands can be designed and managed to be of greatest value to certain target species and the natural evolution of the islands can be controlled for maximum wildlife benefit. However, there are problems. A real problem is the conflicting concerns and needs of the wildlife interests and the fisheries interests, who often have opposing views on the need for islands versus open water. This type of problem can only be resolved on a local, case-by-case basis.

An imagined problem is the widespread belief that once an island is created and inhabited by desirable wildlife, it can never again be used as a disposal site. This is not true. In fact, DMRP studies have shown that unless natural vegetational successional patterns are occasionally interrupted, the islands will lose their wildlife value. The most practical way of providing the needed interruption is by depositing a new layer of material.

Seagrasses have been transplanted successfully on some disposal sites; however, much research is still ahead in this area.

While the DMRP focused primarily on wetland and upland habitats, aquatic or submerged habitats were included. A literature review and a small field test were accomplished, but these concluded only that it is a promising but unproved disposal alternative. It was demonstrated that seagrasses can be transplanted to a disposal site; however, much additional information will be needed before the basic requirements for establishing a successful seagrass meadow are recognized and understood.

The fourth major part of the DMRP was the development and testing of concepts for non-wildlife-oriented beneficial or productive uses of either dredged material itself or disposal sites. Perhaps more than in any other alternative, successful use of the material or the sites as a natural resource requires favorable and often fortuitous circumstances, but these do occur. Non-technical factors outweigh technical ones more as a rule than as an exception and requirements for coordination and cooperation in land use planning are magnified.

Opportunities for the productive use of dredged material increase appreciably as one moves inland from navigable waterways. As a consequence, one DMRP study considered long distance transport of dredged material and is producing a method to use in determining the feasibility and cost of various transport modes for individual projects. If dredged material can be moved overland economically, some of the disposal opportunities that emerge include improvement of agricultural soils, use of dredged material in solid waste management, the filling of abandoned pits and quarries, and strip mine reclamation.

As would be expected, concerns over the effects of using chemically contaminated materials dominate the list of relevant considerations; however, so far these have not proved to be limiting. One should never lose sight of the fact that much dredged material is not contaminated, nor should the real dangers of placing saline dredged materials in freshwater areas be overlooked.

Considering productive uses of dredged material, the DMRP has not overlooked the obvious value of the land created when a disposal site reaches capacity. Most disposal sites filled with the fine-grained materials from maintenance dredging are not suitable for industrial or commercial development from a foundation engineering point of view, but they can be ideally suited for recreation.

The environmental impact of disposal operations, particularly open water ones, is not as severe as has generally been believed. Indeed, with proper evaluation, planning, and management, no disposal operation abiding by current criteria and guidelines should be environmentally damaging. But why stop there? There are many economically necessary dredging projects where the goal need not be just "disposal." Dredged material can be an environmentally safe unused resource. In many cases, all that is needed is imagination and a desire to work together toward effective solutions. Problems still exist, but as a result of the DMRP, many of the ones related to a lack of scientific data have been eliminated. ■

Water & Wastes: A HISTORY

by Joel A. Tarr and Francis C. McMichael

Water supply and waste disposal systems are not necessarily connected. They became so because cities made conscious choices to adopt water-carriage sewer systems. Sewerage solved the immediate problems of waste disposal but ultimately led to new ones that society is still struggling to solve. Here, historian Joel A. Tarr and civil engineer Francis C. McMichael tell how sewerage technology came to be adopted, note how it contributed to the pollution of America's waters, and discuss some of its impacts on government.

Until well into the second half of the 19th century most American urbanites depended for their water supplies upon local sources such as ponds, wells, pumps, and cisterns. Wastewater was disposed of in the most convenient manner available—in a dry well, in a leaching cesspool (a hole lined with broken stone), or sometimes simply by throwing it on the ground. Sewers existed in larger cities, such as New York and Boston, but they were intended for storm water drainage rather than human waste removal. In fact, in some cities ordinances forbad placing human wastes in the sewers. Most cities, however, had no underground drains. Street gutters carried off storm water and urban by-products.

Human wastes were sometimes deposited in cesspools but more usually in privy vaults, which ranged from shallow holes in the ground to receptacles lined with brick or stone. They had limited capacities and had to be replaced or emptied periodically. Most large cities tried to institute periodic cleaning either by private scavengers under city contract or by city employees, but maintenance was primarily an individual rather than a municipal responsibility. The technology for cleaning was rudimentary—dippers, buckets, and wooden casks. The wastes collected by the scavengers were disposed of in nearby waters, dumped on the land, recycled on a local farm, or sold to reprocessing plants to be made into fertilizer. The process was labor intensive and inefficient, creating both aesthetic nuisance and

Dumping wastes into the street—often near drinking water wells—was a common practice in the early 19th century, as illustrated in this 1881 Harper's Weekly *drawing entitled "Sowing for Diptheria."*

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health problems, primarily through pollution of ground water and wells.

Medical opinion split over the source of the health danger. One faction, the contagionists, maintained that disease was transmitted by contact with a diseased individual, while anti-contagionists, in the majority, maintained that the cause was "vitiated," or impure, atmosphere, which could arise from putrefying substances, swamps and stagnant pools, and human and animal crowding.

Breakdown of the Cesspool-Privy Vault System

During the years from approximately 1820 to 1880, demographic and technological factors combined to place a great strain on the cesspool-privy vault system and eventually to cause its breakdown and replacement. U.S. cities grew rapidly in the 19th century, and urban populations became more concentrated, especially in the central cores. The existing waste collection system became increasingly inadequate. Overflowing privies and cesspools filled alleys and yards with waste, and, where they were close to drinking water wells, the pollution hazard was serious.

The technology of piped-in water also increased stress on the cesspool-privy vault system. Piped-in water was introduced for three primary reasons: local water sources had become contaminated and were suspected as sources of disease; more copious supplies were needed for fire fighting; and water was needed for street flushing at times of concern over epidemics. In addition, rising affluence increased households' demands for water.

Hundreds of cities and towns installed waterworks in the first three-quarters of the 19th century, but not one simultaneously constructed a sewer system to remove the water. In most cities with waterworks, wastewater was diverted into cesspools, existing storm sewers, or street gutters. The introduction of such a large volume of water into the system caused serious problems of flooding and disposal. The situation was exacerbated by the unanticipated adoption of a new technology—the water closet.

The water closet, or flush toilet, dates back centuries, but it was patented in the United States only in 1833. In cities with waterworks, affluent families were quick to install it to take advantage of its indoor location and cleanliness, and by 1880 an estimated one-quarter of urban households had water closets. They were usually connected to cesspools or privy vaults, which were soon overcharged by the greatly increased flow of waste-bearing water. Soil became saturated, cellars were "flooded with stagnant and offensive fluids," and much more frequent emptying was needed, increasing the cost of the system.

Modern sewage treatment technology solved old problems, but it has created new ones, which scientists, engineers, and planners are now working to solve. CoE

The spreading of fecal-polluted water also created both real and imagined health hazards. By the mid-19th century, the anti-contagionist "filth theory" of disease was dominant. Putrefying fecal matter was believed to produce "dangerous gases" and "unwholesome vapors." Public health officials viewed overflowing cesspools with water closet connections as an especial threat. Cities attempted to improve the working of the existing system by using devices like the odorless excavator (a vacuum pump used to empty privies), but improvement were minimal, and costs high. The system itself had to be replaced, and in the second half of the 19th century the water-carriage technology of waste removal was the replacement most often considered.

Benefits and Costs of Water-Carriage Technology

The water-carriage system of waste removal (sewerage) essentially uses wastewater itself as a transmission medium and cleansing agent in the pipe. Such a system, designed to handle both household wastes and storm water, was constructed in London in the 1850s and served as a model for American cities.

The new system differed markedly from the cesspool-privy vault-scavenger system: it was capital rather than labor intensive and required the construction of large public works; it utilized batch rather than individual collection; it was automatic, eliminating the need for decisions and actions to remove the wastes; and it was dependent on municipal rather than private financing and maintenance.

The debates over the adoption of water-carriage technology were marked by the conflicting forecasts of its advocates and opponents. Advocates foresaw cost savings and lowered ill-

ness and death rates, which they translated into terms of economic benefits, including faster population and industrial growth, for communities that adopted the new technology and abandoned the cesspool-privy vault system. Opponents predicted higher taxes, health hazards due to contamination of subsoil by leakage, pollution of water (threatening drinking water and shellfish), and the generation of supposedly disease-causing sewer gas. Also, they decried the waste of the fertilizer potential in human excreta.

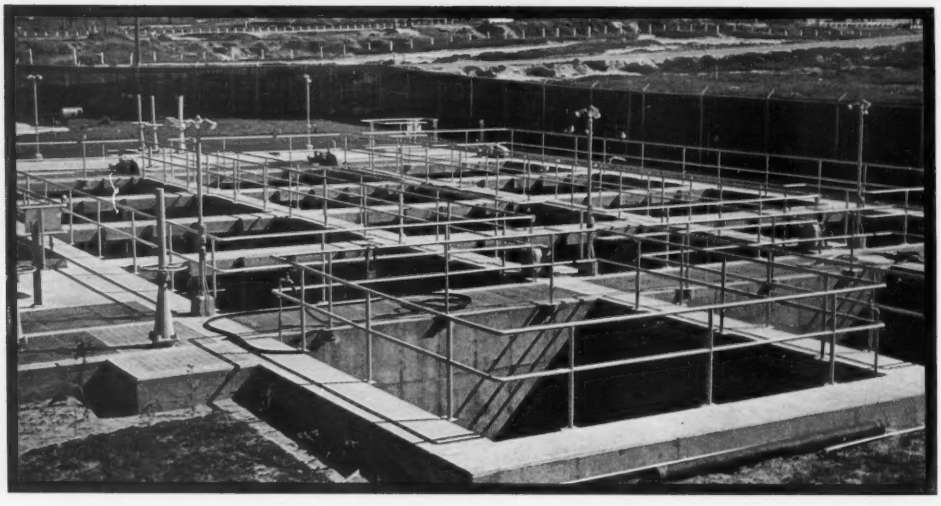
The major gap in the debate concerned the effects that the disposal of sewage into water would have on the water supplies of downstream communities. While a few forecasters warned about the health hazards, they were largely ignored because of the widespread belief that "running water purifies itself." In the late 19th and early 20th centuries, municipalities judged that the promised benefits of the technology outweighed its predicted costs, and they embarked on a massive campaign of sewer system construction. Between 1890 and 1909, for instance, the miles of sewers in cities over 25,000 in population increased from about 6,000 to over 25,000.

Remnants of the waste disposal technology of the 19th century—privy vaults in Pittsburgh, 1910.

The choice between separate and combined sewers was an important question for the engineers designing sewer systems. (Separate sewers consist of two sets of pipes—a sanitary sewer to carry household wastes and a storm drain for rainwater.) The choice between these two systems, which should have been based upon rational analysis of factors such as costs, traffic densities, and rainfall, was complicated in the 1880s and 1890s by confusion over the health effects of the systems. Colonel George E. Waring, Jr., for instance, maintained that the separate system was more healthful than the combined system because the former produced less "sewer gas." During the last decades of the century, a number of small cities, influenced by his advice (and considerations of cost), built sanitary sewers and allowed storm water to run off on the surface. Most large cities, however, faced with the need to remove storm water from the streets, installed combined sewers.

By 1900, most engineers believed that the two designs had equal health benefits, and choices between the two systems were normally made on the basis of costs and the need for subsurface removal of storm water. Thus, in general, large cities with heavy traffic conditions and high

The 20th century's technology developed to solve the problems of the privy vault system. Its concept reflects the values and scientific knowledge of the era in which it was developed. CoE



housing densities built combined systems, while smaller cities tried to get by with separate sanitary sewers only. In 1909, of the total of 24,972 miles of sewers in cities over 30,000 people, some 74 percent were combined sewers and 21 percent were separate sanitary sewers; only 1,352 miles were separate storm sewers.

Although it was not necessarily apparent at the time, the choice of combined sewers, with their greater discharge volume, made both wastewater treatment and resource recovery more difficult and expensive later. Then, however, most urban policy makers and their consulting engineers, assuming that streams were self-purifying, considered disposing of raw sewage in streams adequate treatment. Although serious questions about the validity of the assumption arose in the 1890s, many cities continued to dump their raw sewage into the streams and lakes from which others drew their water supplies. In 1909, 88 percent of the wastewater of the sewered population was disposed of, without treatment, in bodies of water. Where treatment was utilized, it was to prevent nuisance rather than to avoid contaminating the drinking water of a downstream city.

The consequence of dumping untreated sewage into streams and lakes from which other cities drew their water supplies was a large increase in the occurrence of typhoid fever and other infectious water-borne diseases. Atlanta, Pittsburgh, Trenton, and Toledo, for instance—all cities that in the 1880-1890 period constructed sewer systems for their health benefits—experienced substantial rises in typhoid death rates during this same period. In the early 1890s, research clarified the etiology of typhoid fever and left no doubt about its relationship to sewage-polluted water. The irony was clear: anticipated health benefits had been a key factor in the adoption of water-carriage technology, but disposal practices generated serious hazards. But, because these hazards were often borne by second parties or downstream users while the benefits accrued to upstream communities, municipalities continued to build sewer systems and to dump untreated sewage into the water.

Handling the Unexpected Impacts

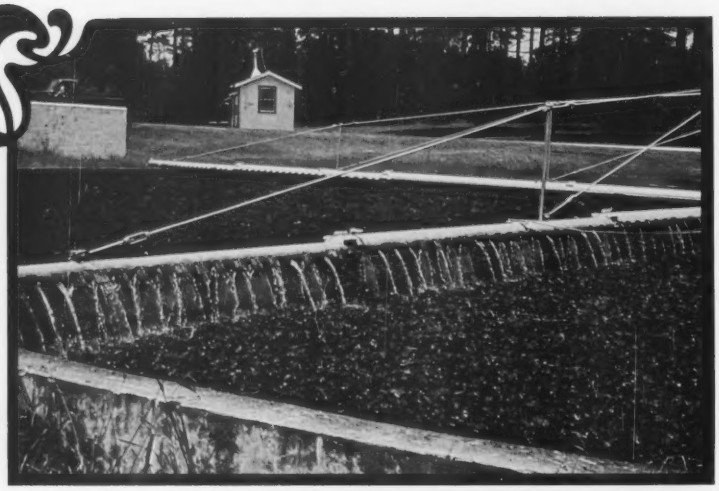
By the end of the 19th century, many American cities had three policy tools for dealing with human wastes and wastewater disposal: local health ordinances, such as sanitary and plumbing codes; boards of health with investigatory and regulatory powers; and sewerage technology. The policies that protected health locally, however, created threats to the health of nonlocal water users. The transfer of the negative impacts of waste material from one community to another necessitated an extra-local governmental response. Legal redress for damages was possible in the case of nuisance, but difficulties in specifying the origins of water-borne disease prevented the victims from seeking court relief. The institutional response took the form of the creation of state boards of health, beginning in Massachusetts in 1869, and the passage of legislation to protect water quality. By 1905, some 36 states had some legislation protecting drinking water, usually administered by the health boards. These regulations, however, often lacked sufficient enforcement provisions and applied only to new systems or to existing systems if they were extended.

A community's water supply, Pittsburgh, 1910.

By the turn of the century, municipal policy makers, public health officials, and sanitary engineers saw several alternatives for meeting the threat of sewage to water supplies. One choice was to obtain water from a distant and protected watershed, a course followed by cities such as Newark and Jersey City, New Jersey. Another option was to use sewage treatment, or "purification," but this benefited the downstream city while imposing costs on the upstream community. Furthermore, treatment technology was rudimentary, and the two methods most commonly used in 1900, sewage farming and intermittent filtration, were land intensive and most feasible with sewage from a separate system. Since the great majority of cities had combined systems, sewage treatment was costly, and only one city with a combined system treated its sewage.

In the late 1890s, however, another option had appeared—water filtration. After research had showed the effectiveness of both sand and mechanical filters in treating sewage-polluted waters, many inland cities installed filters, and there followed an impressive decline in the occurrence of typhoid fever and other diseases.

The choice then confronting municipalities and health authorities was whether cities should



Before sewerage was installed, municipalities relied on scavengers to empty cesspools and privy vaults.

both filter their water and treat their sewage, thus protecting their own water supply and those of downstream communities, or only filter their water, leaving downstream users to fend for themselves. Debate, centering on protecting both the public health and the financial integrity of municipalities, caused a major rift in states such as New York and Pennsylvania between state boards of health, favoring both water filtration and sewage treatment, and consulting sanitary engineers and their municipal clients, favoring filtration only. This dispute took place from about 1900 to 1914, and its resolution set the pattern for dealing with water pollution problems and the public health into the 1930s.

In a number of cases during the years 1905 to 1914, state boards of health attempted to compel municipalities to stop discharging untreated sewage into streams. Where the problem was one of nuisance, municipalities usually constructed sewage treatment plants in order to avoid legal claims. In cases involving alleged threats to water supplies, however, boards of health were, for the most part, unable to change municipal practice and compel sewage treatment. The municipalities received the support of the engineering profession, which, the *Engineering News* maintained, was more aware of the "relative needs and values of municipalities" than were physicians and so was better equipped to decide questions about water supply and sewage disposal. "It is often more equitable to all concerned," *Engineering News* wrote, "for an upper riparian city to discharge its sewage into a stream and a lower riparian city to filter the water of the same stream for a domestic supply, than for the former city to be forced to put in sewage treatment works."

By the beginning of the First World War, the perspective of the sanitary engineers had triumphed over that of groups who opposed use of waters for sewage disposal purposes. Essentially, the engineering position was that the dilution power of streams should be utilized to its fullest extent for sewage disposal so long as no danger was posed to the public health or property rights and no nuisance was created. Water filtration and/or chlorination would serve to protect the public from waterborne disease. Filtration and chlorination did, in fact, diminish the occurrence of water-borne infectious disease, and, by 1930, the earlier crisis atmosphere that had led to the first enforceable state legislation had disappeared. The result was that, by 1930, not only did the great majority of the urban population dispose of its sewage without treatment, but the proportion doing so was growing relative to that of people treating their sewage before discharge. And, in the 1910-1930 period, the growth of water filtration was even greater than the rate of sewer installation. (See Figure 1.)

Effects on Government

Sewer systems have characteristics of economies of scale and continuous collection that often ignore municipal boundaries and make them centralizing mechanisms. The same disregard of political boundaries is characteristic of the health hazards created by waste disposal and water pollution. Ideally, then, wastewater collection and disposal should be dealt with on a regional basis, but most American urban areas were (and are) characterized by political fragmentation. In order to secure cost and design advantages, as well as efficiency and safety of disposal, sanitary engineers and public health officials pushed first for regional cooperation in sewer and water services and later for new regional administrative arrangements.

Three means to overcome the fragmentation of jurisdiction came into use: intermunicipal and interstate cooperation, annexation or consolidation of suburban areas with a central city, and special district governments. The chief example of intermunicipal cooperation was the Passaic Valley Sewerage and Drainage Commission, in which seven northern New Jersey municipalities joined in 1902 to construct a joint outlet sewer. Few areas followed this example, however, because of the difficulty of obtaining agreement on apportioning responsibilities and costs. The same problem hindered development of interstate water pollution compacts before 1920; in the second quarter of the century, however, such compacts were instituted in important regions such as the Ohio River Valley.

The annexation or consolidation of suburban territories by a central city was a more common method of solving intergovernmental sewerage

A scavenger's wagon in Baltimore, 1911.

problems. The economies of scale of sewer and water supply systems enticed suburban communities to consolidate with central cities that could supply these services. The suburbs were particularly vulnerable to such inducement because they lacked the tax base to provide capital-intensive services. As a further inducement, the annexed territories often received these services at the regular city rate, even though the costs of installation exceeded revenues.

The most common institutional means of handling sewer and water supply projects has been the special district government. These are special state creations, fiscally and administratively independent authorities of limited function and jurisdiction. Behind their creation was the need for a functional structure independent of political boundaries, a desire to escape existing tax or debt limits, and a wish to be free of municipal political control. Also, special district governments were an alternative to annexation, and so preferred by suburban authorities.

Planning and Administration

The new technology required a permanent bureaucracy for day-to-day administration, data collection, and efficient planning for long-term needs. The massive costs of these public works demanded fiscal planning by disinterested professionals. In addition, the works could be constructed most efficiently by experts who could survey the topography scientifically, evaluate alternative materials, and design the physical facilities. Thus the adoption of water and sewer systems encouraged the development of technocracy.

The "odorless excavator," a vacuum pump for emptying privy vaults and cesspools, proved inadequate to handle the increased volume of waste water that resulted from the introduction of running water.

Before the Civil War, and long before the city planning movement began, every major exposition on sanitary reform argued the virtues of planned sewerage. By the 1870s and 1880s, this form of planning was firmly established, and sanitary engineering had become an important branch of civil engineering. While the engineer's view of planning was restricted to sewage collection and disposal and water supply, inherent in it was the concept of the city as a physical container to be organized so as to provide more efficient delivery of services and disposal of wastes. The engineering ideal was the comprehensively planned city, staffed and managed by disinterested experts.

Planning involves making predictions and dealing with probabilities and uncertainties, and sanitary engineering, more than other branches

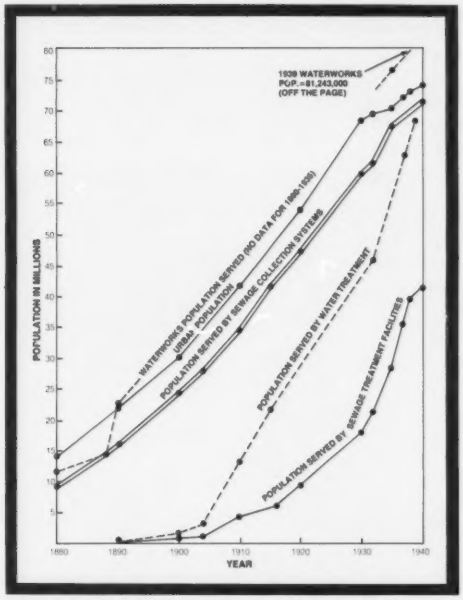
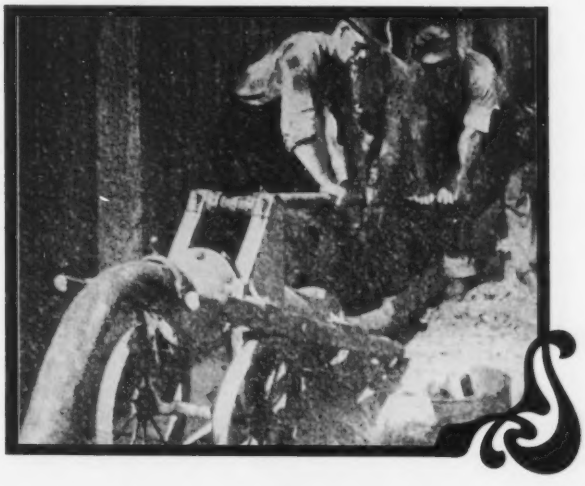


Figure 1. U.S. Urban Population, Water Treatment, and Sewage Treatment, 1880-1940.



Land treatment is again being investigated. Here, wastewater from campgrounds at Deer Creek Lake, Ohio, is sprayed on a field as the final step in an innovative treatment process. The facility was built by the Corps of Engineers' Huntington District and is operated jointly by the Corps and the Ohio Department of Natural Resources. CoE

of the field, had to deal with these factors. Sanitary engineers were concerned with rainfall prediction, water usage, and demographic change, all factors characterized by high uncertainty; they were the first to attempt long-range urban population predictions, doing so considerably before city planners.

The experience of sanitary engineers with population forecasting, behavioral factors such as water usage, and public health considerations, as well as their experience in planning large-scale capital works, suited them well for key roles in city government. They adhered to a set of values and procedures that stressed efficiency within a benefit-cost framework, and this appealed to late 19th and early 20th century reformers attempting to restructure municipal government in the direction of professionalism, efficiency, and bureaucratization. Sanitary engineers served in city government not only as municipal engineers but also as administrators; they were a principal group from which city managers were recruited before World War II.

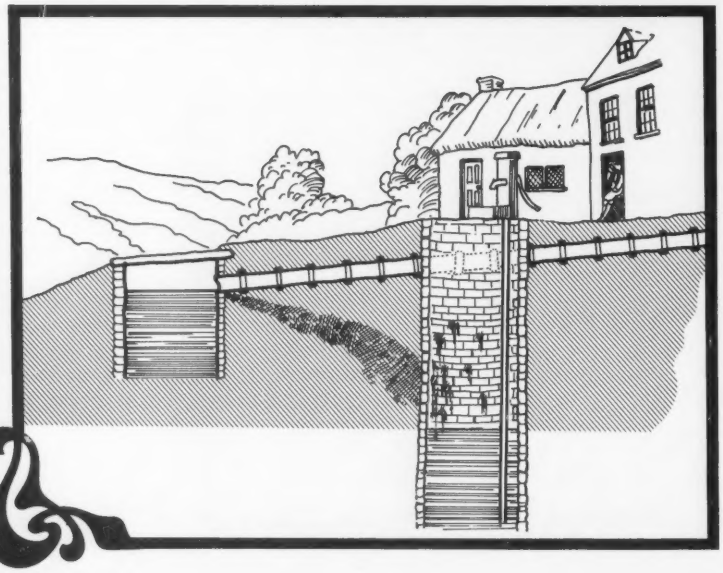
Sewers were often no more than open channels in the street, like this one in Duquesne, Pennsylvania, photographed in the early 20th century.

The history of waste disposal technology suggests several observations about technology and public policy.

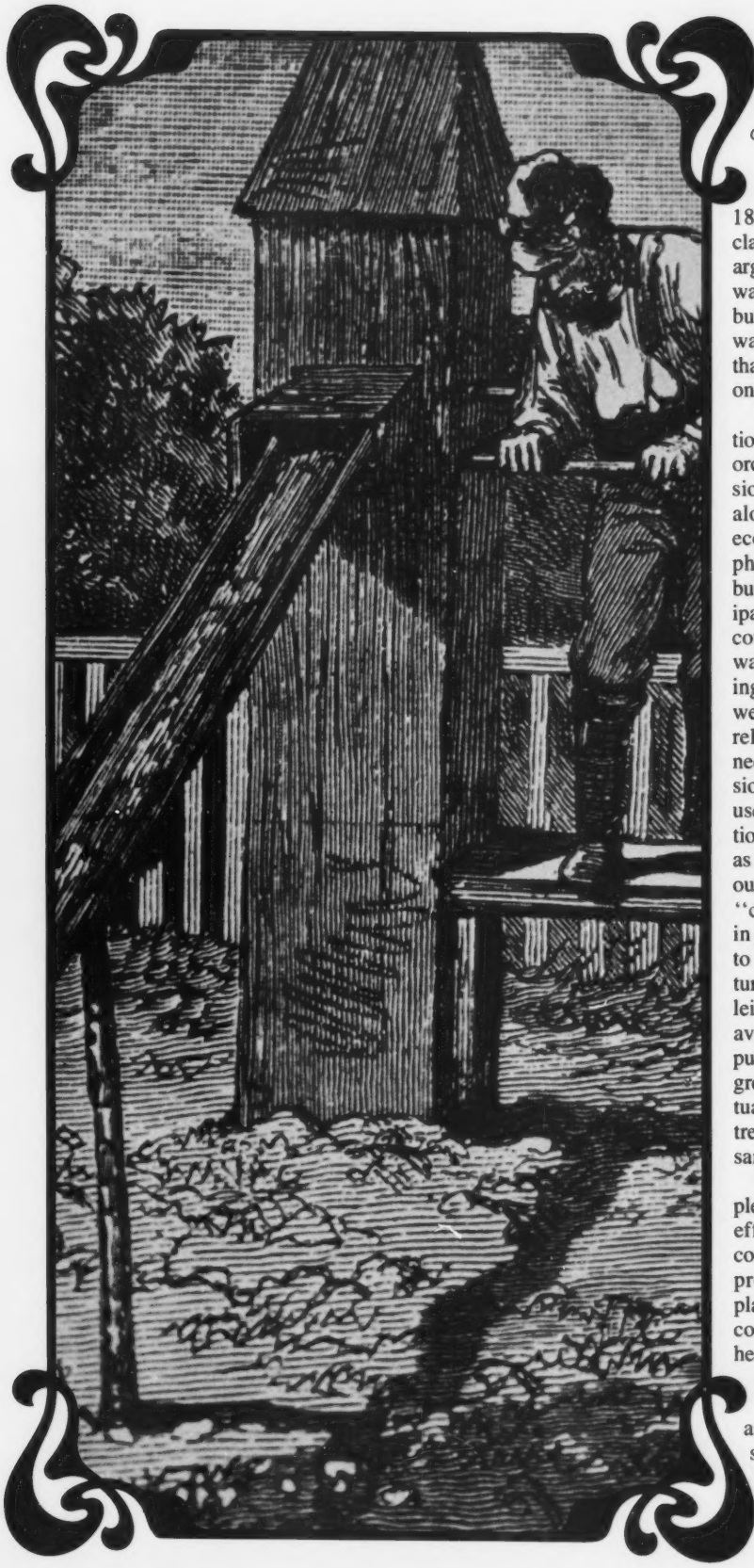
Introduction of public water supplies into cities led to the unexpected adoption of the water closet; the negative consequences illustrate the risk of introducing new elements into a balanced technological system without calculating its impacts. To anticipate impacts, policy makers must understand the operations and interrelationships of the existing system.

The choice of sewerage to replace the cesspool-privy vault system was based on forecasts of the benefits and costs of the new technology. Sewerage, it was claimed, would produce benefits in the areas of health, finances, and urban growth. In the rush to adopt the new technology, warnings of costs in regard to wasted resources, expense, and health were largely disregarded.

The choices of sewer system design—separate or combined and treatment or no treatment—were also made according to a benefit-cost calculus. But the calculations were based partly on faulty scientific concepts. In the 1870s and



Growing awareness of the hazards of the cesspool system—as evidenced by this sketch from the Pictorial Guide to Domestic Sanitary Defects, *published in London in 1874—propelled the search for a better means to dispose of human wastes.*



Using sewage as fertilizer never caught on with municipalities as a disposal method. This illustration from Harper's Weekly *in 1881 shows sewage being pumped for use on a farm.*

1880s, advocates of separate sewers, who claimed they prevented sewer gas formation, argued from a theory of disease transmission that was without scientific proof. And large cities built combined systems and discharged their wastes into bodies of water on the assumption that streams were self-purifying, a concept true only under very specific and limited conditions.

When it came to choosing between filtration and both filtration and sewage treatment in order to protect water quality, differing professional values came into conflict. Engineers, along with municipal officials, emphasized economy in meeting water quality goals, while physicians often stressed safety but ignored budgetary constraints. The engineers and municipal officials, whose position usually triumphed, could argue against sewage treatment because water filtration and chlorination protected drinking water supplies, because municipal budgets were restricted, and because recreation held a relatively low priority compared to other urban needs. As the New York Conservation Commission noted in 1923, recreational and industrial uses of streams were incompatible, and recreation "usually causes pollution of the water such as to unfit it for drinking." Man could live without recreation, added the Commission, but he "could not and should not live without work; so, in general, recreational purposes are subordinate to the other uses of water." However, after the turn of the century, as growing affluence and leisure time made recreation increasingly more available to the middle and working classes, the public's appreciation of water for recreation grew. This was an important factor in the eventual move to retrofit sewer systems by installing treatment facilities and separating storm and sanitary sewers.

Ultimately, water-carriage technology, complete with retrofitting, may have been the most efficient and cost-effective system that society could have devised to deal with its waste removal problems. Retrofitting, however, has taken place in an incremental manner and only after considerable damage has been done to the public health and the environment. Furthermore, the existence of this capital intensive system throughout urban America has been accepted as an unchangeable fact, and until recently had stifled the search for alternatives. Thus society continues to struggle with the problems of a waste removal technology based on concepts over a century old. ■

WATERWAY RECOVERY

by John Cairns, Jr.

Surface strip mining, the eutrophication of Lake Erie, recurring major oil spills and similar ecological disasters have drawn increasing attention to the urgent need for restoration of presently damaged or degraded ecosystems.

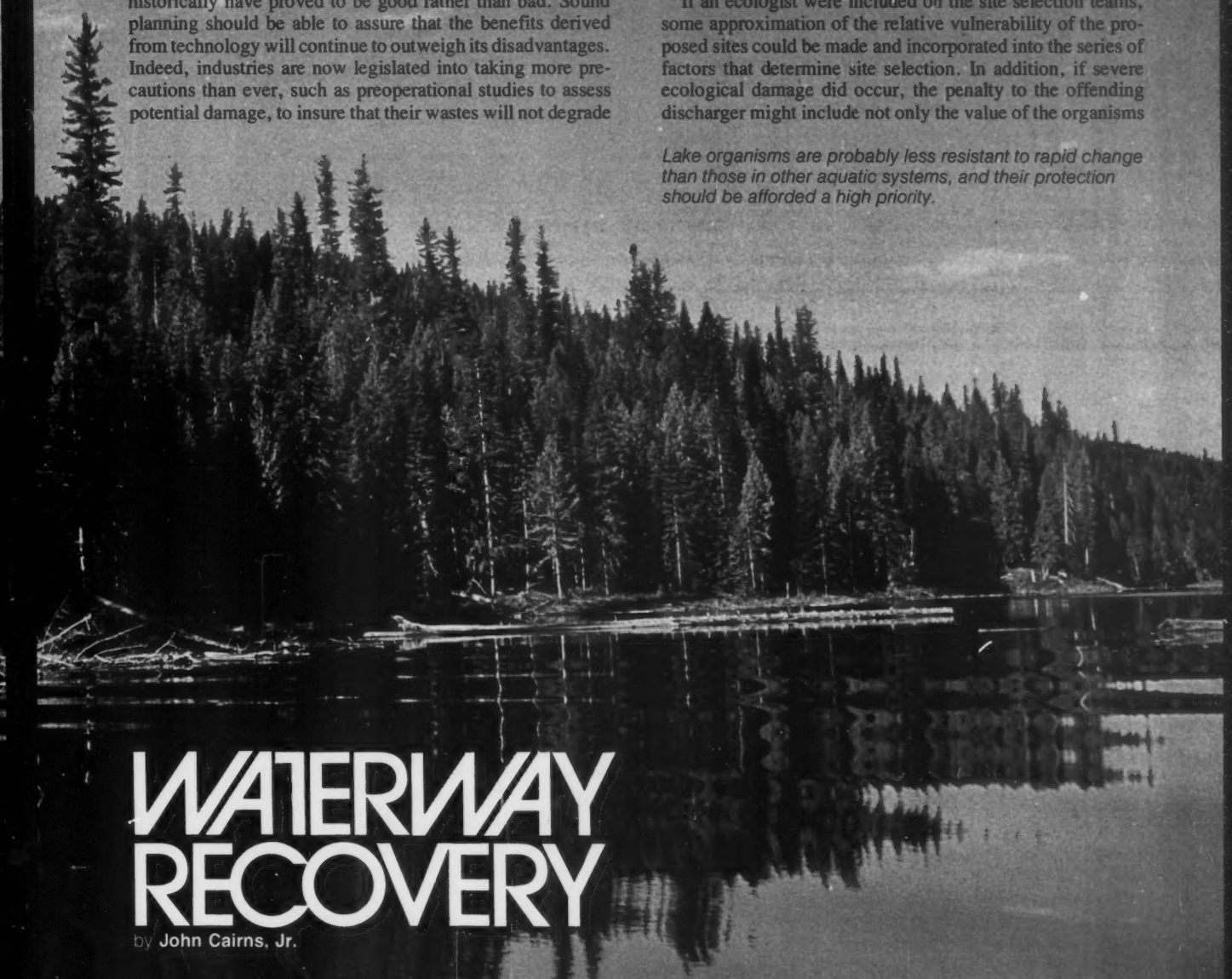
The future of all ecosystems depends upon man; ironically the future of man also depends upon the life supporting ecosystems. There exists no reason to believe that the current ecological situation represents an unfortunate state that is incapable of improvement through conscientious, intelligent management.

Although technology may now be going through a period in which its bad effects offset the good achieved, its effects historically have proved to be good rather than bad. Sound planning should be able to assure that the benefits derived from technology will continue to outweigh its disadvantages. Indeed, industries are now legislated into taking more precautions than ever, such as preoperational studies to assess potential damage, to insure that their wastes will not degrade ecosystems, and that accidental spills of toxic materials may be avoided.

It is quite likely that even if adequate preoperational studies are carried out—and accompanied by ecological monitoring programs—some accidents will occur due to spills such as the ones reported in 1971 and 1972 by the author on southwestern Virginia's Clinch River. Some means of estimating the elasticity of an aquatic ecosystem (its ability to recover following severe stress) is badly needed. Such an index would be useful, not only following accidental damage, but in estimating the ecological vulnerability of various sites proposed for development.

If an ecologist were included on the site selection teams, some approximation of the relative vulnerability of the proposed sites could be made and incorporated into the series of factors that determine site selection. In addition, if severe ecological damage did occur, the penalty to the offending discharger might include not only the value of the organisms

Lake organisms are probably less resistant to rapid change than those in other aquatic systems, and their protection should be afforded a high priority.



Dr. Cairns is the Director, Center for Environmental Studies, Virginia Polytechnic Institute and State University, Blacksburg, Va. This article is adapted from a National Planning Association position paper of his authorship.

killed and amenities lost, but be prorated over the length of time the ecosystem would be severely damaged.

A brief review of aquatic ecosystem types is now in order:

Lakes:

An important characteristic of temperate zone stratified lakes—this includes most of the important lakes in the United States—is the periodicity of the striking changes within the system. These lakes typically become thermally stratified during both summer and winter "stagnation." The three resulting layers (the epilimnion or surface layer, the thermocline or intermediate layer, and the hypolimnion or bottom layer) are quite distinct from each other in chemical, physical and biological characteristics. During the spring and fall of each year when the surface water is at its greatest density, the whole lake "turns over." These turnover periods are "expected" by the lake biota and any interruption, such as the discharge of heated water from a powerplant, might have

Point source pollution has a dramatic, and often residual, effect on an aquatic ecosystem's degree of elasticity.

biological consequences out of proportion to the physical-chemical value of the change.

A second characteristic of lakes is that they act as nutrient traps in which phosphorous and other nutrient materials accumulate and contribute to the aging, eutrophication process. There is a degree of irreversibility of any part of the aging process, but the Lake Washington (near Seattle) story has shown that restoration to a much better condition is possible. Except for the turnover periods, the environment of lakes tends to be considerably more stable than that of rivers and estuaries. As lake organisms are probably not as resistant to rapid short term changes as riverine and estuarine species, lake protection should enjoy a high priority.

Rivers:

Flowing rivers initially receive the major portion of all discharged wastes entering the aquatic systems of the United States. Their ability to cleanse themselves is well known, but may be markedly changed when their environmental structure is altered (e.g. from flowing to standing water) following the construction of hydroelectric and flood control reservoirs. Some Kansas reservoirs, for example, become eutrophic before reaching pool level as the result of runoff from cattle feedlots contributing enormous amounts of nutrients in a short period of time.

The elasticity (ability to "snap back" from displacement) of river ecosystems can be phenomenal under certain conditions. However, wastes discharged into rivers will sometimes be carried to lakes and, inevitably, to estuaries and eventually the ocean. These latter systems are much less able to recover from displacement. The fact that river water may be used and reused many times before reaching the oceans is another compelling reason for lessening the waste discharges therein.

Estuaries:

Estuaries are probably the most productive ecological systems in the world, and while the number of species is usually appreciably less than in oceans or rivers, the proportional biomass is larger. This relationship is depicted in Figure 1. As a result of constant change (i.e. temperature, salinity, dissolved oxygen) organisms in estuarine systems probably have the greatest inertia of those in any water ecosystem and an enormous ability to resist disequilibrium. Once in disequilibrium, however, the distance of other estuaries from which the "seed" organisms must come tends to hamper a return to normal conditions. Estuaries represent the ultimate bio-filter—a most important means of degrading river-borne wastes before they reach the oceans.

Oceans:

The oceans represent the ultimate in water environment stability. It appears highly probable that the vast ocean ecosystems are quite fragile, however, and are protected primarily by their vastness and the resultant dilution of all potentially deleterious materials. Should an entire ocean be damaged, the time required for recovery staggers the imagination, especially since many of the organisms are highly vulnerable to change and presumably would not be able to withstand the rigors of invading new areas far from their original habitat.

The destruction of algal growth in a body of water can have serious effects on its dissolved oxygen content, and thus its animal organisms.

The matrix labeled Table 1 represents an attempt to categorize our four primary water systems (lakes, rivers, estuaries, and oceans) in terms of their vulnerability to irreversible effects, the severity of the environmental stresses to which they are now exposed, and the frequency of the man-originated perturbations to which they are now exposed. (Table 2 provides a crude estimate of the elasticity, inertia and environmental quality stability of the four ecosystems under discussion.)

A list of factors contributing to rapid recovery may be ascertained from studies of the Aquatic Ecology Group at Virginia Polytechnic Institute in the late 60s and early 70s. It

Table 1.[a] *Relative vulnerability of four water ecosystems to irreversible effects; the severity of stress presently resulting from man-originated activities; frequency through both space and time of man-originated perturbations. Low number = worst effects.*

	Irreversibility of Effects	Stress Severity	Frequency of Man-Originated Perturbations	Total
Lakes	2 (20)	3 (80)	3 (80)	8 (180)
Rivers	3 (80)	2 (50)	1 (1)	6 (131)
Estuaries	4 (100)	1 (1)	2 (40)	7 (151)
Oceans	1 (1)	4 (100)	4 (100)	9 (201)

[a]*Reproduced with permission from the University Press of Virginia; from Cairns, Dickson, and Herricks, 1977.*

Flowing rivers bear the brunt of discharged wastes entering the aquatic systems of the United States.

is quite likely that the factors are sufficiently general to apply to terrestrial and marine ecosystems as well as freshwater ecosystems. However, it should be noted that the influence of residual toxicity or altered conditions would be markedly different for standing water, such as lakes, than for flowing waters. Nevertheless, despite this differential that exists due to the ecological disparity of the systems, the factors to follow are undoubtedly important in each.

The ordering of the factors important to the recovery process was deliberate, and indicates their importance in the process. In view of our present lack of substantive knowledge regarding the recovery process, it seemed ludicrous to attempt a more elaborate equation. On the other hand, it is quite clear that there is a "multiplier" effect between the factors involved (see recovery index equation below), and that some of the factors—such as management or organizational capabilities—are of little importance if there is nothing to work with. The factors which I consider of greatest importance follow, with a brief discussion of each:

a. Existence of nearby epicenters (e.g., for rivers these might be tributaries) for providing "seed" organisms to reinvade a damaged system. Rating system: 1 = poor; 2 = moderate; and 3 = good.

In a series of studies on the Clinch River, by the author and others, it was clear that in the initial stages of the recovery process some tributaries contributed more organisms to aid in the process than others. It was also evident that some of the organisms recolonizing damaged areas came from the headwaters of the main stream itself. The presence of the comparatively healthy tributaries and headwaters which furnished recolonizing organisms to damaged areas was a key factor in the very rapid recovery which occurred. These tributary and headwater areas might be considered epicenters from which organisms departed to invade and subsequently recolonize the damaged areas. A substantial reduction in the sources of potential recolonizing organisms would have undoubtedly altered the recovery pattern of the Clinch. Therefore, the epicenters are a prime factor in recovery of a damaged system—since without new potential colonizers the process obviously cannot occur.

b. Transportability or mobility for movement dissemules (the dissemules might be spores, eggs, larvae, flying adults which lay eggs, or any other stage in the life history of an organism which permits it to either voluntarily or involuntarily move to a new area). Rating system: 1 = poor; 2 = moderate; 3 = good.

The Clinch River studies showed quite clearly that some groups of organisms have a greater potential for becoming reestablished in a damaged area than others. Fish, for example, moved into the damaged areas soon after the fly ash pond spill occurred which temporarily destroyed the biota of over a hundred miles of river. The same held true for the acid spill which occurred sometime later but which affected a more limited area. Aquatic insect larvae, which "drift" downstream and are, therefore, good recolonizers, also became reestablished rather soon.

Conversely, the molluscs are rather slow to reinvade, and at the time this article was being prepared there were mollusc species which had not returned to the damaged areas although quite a few years have passed since the last spill. If the damaged community consisted almost entirely of organisms with a high degree of transportability of dissemules, the prospects for recovery would be high. If it consisted primarily of those not easily transported, and thus less likely to reinvade, the prospects of recovery would be rather poor.

Table 2. *The relative elasticity (ability to return to normal after being displaced or placed in disequilibrium), inertia (ability to resist displacement or disequilibrium), and environmental stability (consistency of chemical-physical quality).*

	Elasticity	Inertia	Environmental Stability
Lakes	2[a]	3	2
Rivers	1	2	3
Estuaries	3	1	4
Oceans	4	4	1

[a]Key: 1 = high
2 = intermediate high
3 = intermediate low
4 = low

The most productive ecological system in the world is the estuary, and it also serves at the ultimate bio-filter for riverborne wastes.

c. Condition of the habitat following pollutional stress. Rating system: 1 = poor; 2 = moderate; 3 = good.

The fly ash pond spill and the acid spill on the Clinch River had marked effects on the indigenous biota, but only minimal effects on the physical habitat of the river and a temporary effect on the chemical characteristics of the water. On the other hand, extensive siltation which blanketed the riffle areas would have resulted in marked alteration of the habitat which might persist for a substantial period of time.

d. Presence of residual toxicants following pollutional stress. Rating system: 1 = large amounts; 2 = moderate amounts; 3 = none.

The two Clinch River spills changed the *pH* of the river—one to a high *pH,* the other to a low. In both places the "slug" of water, differing markedly from the ambient *pH,* flowed through the river system leaving no residual toxicants or toxic conditions. Conversely, the intrusion of biocides (e.g. Kepone, dieldrin, aldrin, mercury, or lead) would almost certainly leave residuals which would persist in the system for a considerable length of time.

The presence of residual toxicants might well impair the recovery of a damaged ecosystem by maintaining toxic conditions unsuitable for potential recolonizing organisms. Thus, the presence of such residual toxicants should result in a decrease in the recoverability of a displaced system.

e. Chemical-physical environmental quality following pollutional stress. Rating system: 1 = in severe disequilibrium; 2 = partially restored; 3 = normal.

In some cases the pollutional stress, either through actions in the substratum or other portions of the system or through direct effects on the biota, will put the chemical-physical environment of an ecosystem into severe disequilibrium. For example, a reservoir or lake with a substantial algal growth might normally have a dissolved oxygen concentration at saturation during daylight hours, and well above 2 or 3 ppm even during the longest periods of darkness. If, however, these plants were destroyed by a toxic stress, the additional decaying load thus added, together with the absence of plants as a source of oxygen, might produce a change from aerobic to anaerobic conditions in certain parts of the system. If one assumes that the recovery process will involve a return to an approximation of the original condition, this system could

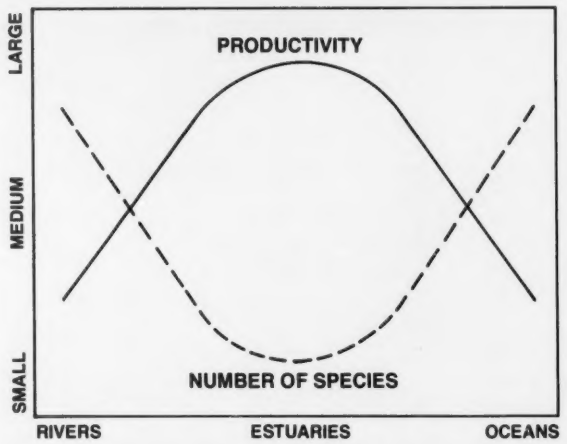


Figure 1. Relationship of number of species in estuaries, oceans, and rivers.

then be considered either displaced or in disequilibrium relative to its original condition.

In systems such as the Clinch River, where the flow through rate was quite high, this restoration process required only a few hours because the offending material was rapidly removed from the original spill site. On the other hand, a substantial portion of the river biota was damaged during the passage of the slug. The return to an approximation of the chemical-physical conditions originally present is an important prerequisite for the reestablishment of a community characteristic of that particular locale.

f. Management or organizational capabilities for immediate and direct control of the damaged area. Rating system: 1 = none; 2 = some; 3 = thriving, with strong enforcement prerogatives.

In some cases river drainage authorities or other management groups exist which may be capable of aiding the recovery process. For example, if an oxygen disequilibrium exists in a reservoir or lake, an approximation of the normal oxygen regime might be achieved by artificial aeration. This would presumably enhance the conditions for reestablishment of organisms characteristic of that system, including algae and

other plants, and thereby enable the natural balance to be restored sooner than might otherwise occur.

The clean-up of oil spills by organizations charged with the management of a specific ecosystem is another example of such an activity. Reintroduction of certain species not likely to reinvade the area on their own is another, albeit simplistic, example of management intervention in the recovery process. Probably the most valuable contribution a managerial organization could provide is the documenting of baseline or "normal" conditions, so that the degree of disequilibrium can be established when an accident occurs. Some of this data gathering can be automated, thus reducing the time of information generation and the cost.

When the degree of displacement from normal is known, the necessary corrective steps are usually reasonably clear and the available resources can be efficiently directed toward the desired goals. As the organizations charged with the ecosystem management become stronger, their role in the recovery process will become increasingly important.

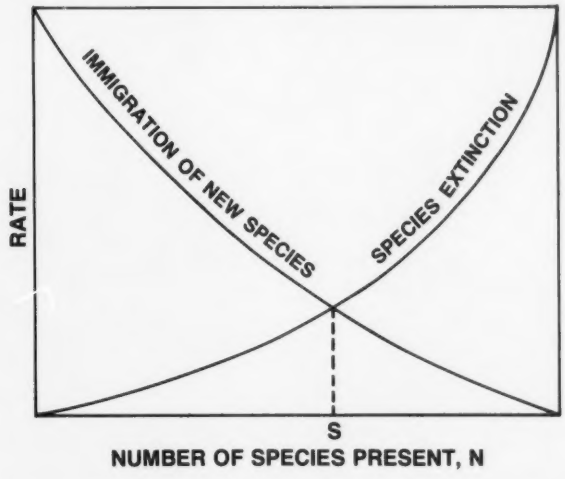
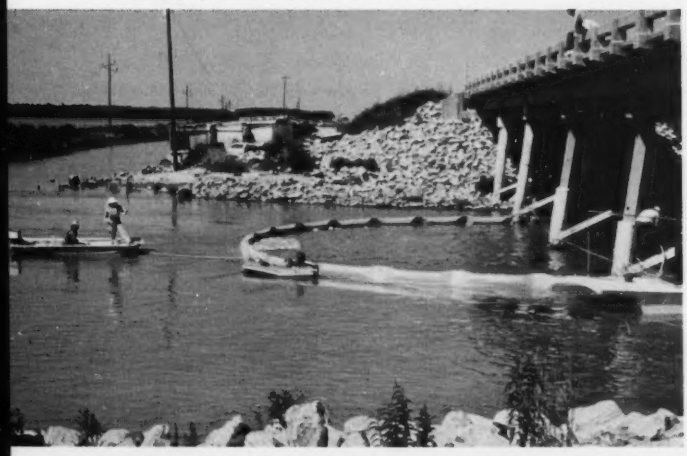


Figure 2. Schematic of colonization and extinction rates.

The corrective actions used as illustrations were relatively simple and straightforward. However, knowing *which* corrective action to take requires a fairly substantial knowledge of the system and a relatively large pool of background data regarding its "normal" condition. This is probably where most management groups fail.

Oil spill recovery technology underlines the axiom that "necessity is the mother of invention."



Developing a Recovery Index

Using the "a" through "f" factors listed above, one can now arrive at a rather crude approximation of the probability of relatively rapid recovery from displacement. This would mean that somewhere between 40% and 60% of the species might become reestablished under optimal conditions in the first year following a severe stress, between 60% and 80% in the following year, and perhaps as high as 95% of the species by the third year.

Natural processes with essentially no assistance from a management or river basin group accomplished this on the Clinch River spills which were studied by VPI. The usefulness of this estimate has also been checked with data provided by some acid mine drainage studies and seems adequate in this regard as well. The equation follows:

RECOVERY INDEX $a \times b \times c \times d \times e \times f$

400+ : Chances of rapid recovery excellent

55-399: Chances of rapid recovery fair to good

Less than 55: Chances of rapid recovery poor

During the development of the simplistic equation just given, considerably more complicated equations were considered and rejected because the refinements seemed meaningless in view of our present state of knowledge. On this basis, one might reject even the modest effort just made. On the other hand, there seems to be a very definite need to formalize the estimation of recovery, and one hopes that more precise equations properly weighted will evolve from this modest beginning.

"State of the Art"

Although there is a fair amount of work on the recovery of damaged ecosystems in which the study focuses on the return of a single species—there is very little substantive evidence on the restoration of communities. Again, a very serious deficiency in this regard is the lack of background information on the original or baseline condition of the system before development began.

One can only speculate about the nature of the aquatic communities and the chemical-physical conditions in the Ohio River before the area became industrialized. This appears to be true both for systems which have become degraded slowly, and therefore engendered no sense of urgency, and for those for which the degradation is swift and unexpected—such as the oil spills at Santa Barbara and other similar incidents.

In some few cases, for example the baseline studies carried out by the Philadelphia Academy of Natural Sciences for most Dupont plants constructed since the late 40s and early 50s, both preoperational and postoperational evidence is available. Techniques and methods for such studies have been available for years but have only been infrequently used.

The conceptual framework also exists for evaluating both natural and manmade perturbations. In cases such as Krakotoa, a volcanic island in the Dutch East Indies which erupted in the late 19th Century, there was some preperturbation evidence on at least the birds and some of the plants characteristic of the island. It is known that the number of species of birds after the eruption eventually reached the number of species that existed before the event, although the species were not entirely the same.

The ability of riverine systems to cleanse themselves is often strained. Primary and secondary sewage treatment is an obvious answer.

Several studies have shown that a reasonably stable number of species (and oscillation of this number within predictable limits) is characteristic of natural systems and is a function of the balance between colonization rate and extinction (perhaps a better word would be elimination) rate. A schematic of this is given in Figure 2.

There is evidence that this equilibrium can be restored, after displacement, by natural processes if these are not blocked. Unfortunately, the number of people working in the field is so small and the number of ecosystems being examined so minute, that it is not feasible now to make precise predictions about the recovery process—except under very specific conditions and circumstances, in ecosystems for which a substantial body of appropriate information exists. For larger systems such as the oceans and the Great Lakes and probably larger rivers such as the Amazon, the rate at which equilibrium conditions might be restored following severe perturbations is wildly speculative, and there is no firm evidence that the equilibrium conditions which would result after displacement from present conditions would resemble them very closely. A symposium on the recovery and restoration of damaged ecosystems* addressed this general subject for a variety of ecosystems—tropical, temperate, polar-terrestrial, and water. Although case histories were available for each general category of ecosystem, they were not abundant.

If one assumes that some of the demands of the underprivileged are to be met and the growth of the world population will continue for the foreseeable future, then multi-source stress on ecosystems will intensify.

At the present time, some of these water ecosystems are sufficiently degraded to curtail many of their benefits to society, and partial restoration seems mandatory for several reasons:

- As the restrictions on energy consumption become more severe, recreation close to home will be increasingly important and water is very frequently a focal point for a variety of types of recreation;
- The use of the flowing water ecosystems to transport wastes away from one's doorstep has probably never been ethically justifiable, particularly when the wastes pass a lot of other "doorsteps" enroute to the ocean;
- Degraded systems lose their ability to transform wastes and, if the transformation process is feasible, the sooner it occurs once the wastes enter the natural ecosystems, the better.

Restoration to a functional condition capable of transforming wastes efficiently, therefore, should be the minimal desired goal.

A river may be viewed both as a utility and as an amenity. As an utility it furnishes municipal and industrial water, serves in cargo transport, "polishes" wastes, etc. As an amenity, it serves for recreation and as a focal point in many activities pleasurable to us all. Protecting a river (or other water ecosystem) as a utility will inevitably improve the amenities.

Protecting our water ecosystems for their utilitarian values will directly enhance their amenity/recreation values.

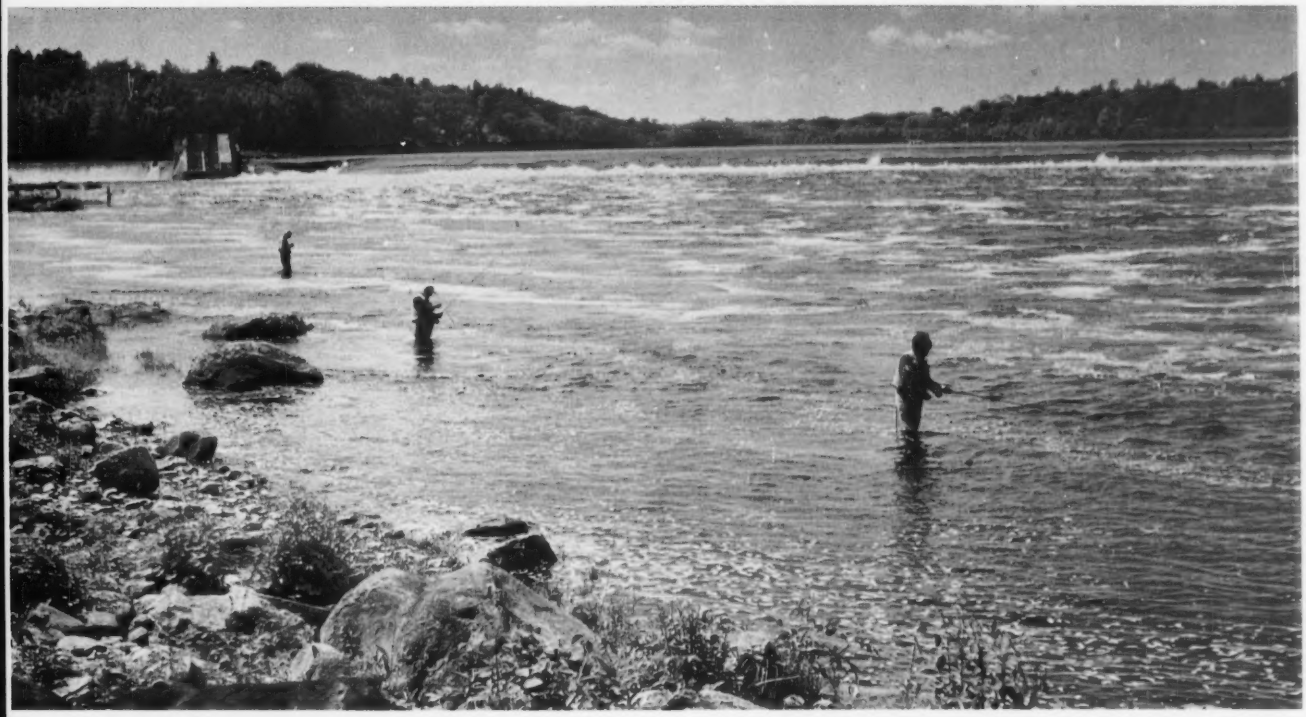
The British are justifiably proud of the restoration of the Thames—which was once malodorous and unsightly. The economic and other practical benefits of this policy are abundantly clear. Although further improvement as a utility is always possible, the major goals have been achieved. Much more improvement as an amenity is at least theoretically possible. For example, should the salmon run be restored? If this were done would the new use conflict with others (e.g. boating)? Cost/benefit ratios are extraordinarily difficult to calculate. Nevertheless the public must be given some idea of the cost of restoring both utility and amenity aspects.

In the United States and most of the industrialized world, first stage restoration of most of our damaged water ecosystems would improve both utility and amenity aspects. Lake Washington and the Thames show that restoration can be accomplished with existing technology at a socially acceptable cost and with benefits that far outweigh the costs. The question is not can we afford restoration but rather can we afford not to restore those water ecosystems that are now severely damaged? ■

*Cairns, J., Jr., K. L. Dickson, and E. E. Herricks, eds. 1977. *Recovery and Restoration of Damaged Ecosystems*. University Press of Virginia, Charlottesville, 531 pp.

Return of the Atlantic

by **Dan C. Kimball and Lawrence W. Stolte**



The Atlantic salmon *(Salmo salar)* is an anadromous species in that it is born in a freshwater river environment, grows to maturity in the ocean and returns to its natal river only to spawn and renew the cycle. Juveniles hatch in the spring and usually spend two years in their ancestral river while growing to approximately six inches in length. They then undergo a physiological transformation called smoltification that sets the stage for life in the marine environment. The young smolts migrate seaward, and spend, typically, two years feeding in the North Atlantic before returning to their natal stream as eight-to-twelve pound adult spawners.

Dr. Kimball and Mr. Stolte are fishery biologists with the Fish and Wildlife Service, U.S. Department of the Interior.

Unlike its Pacific cousin, the Atlantic salmon does not inevitably die after spawning, and many post-spawn fish—called kelts—return to the sea. A small percentage of any spawning run, therefore, may be composed of particularly large salmon that are actually repeat spawners.

Historical Perspective

The Atlantic salmon rivaled the cod as an important and reliable source of protein to the early New England colonists. Its spectacular leaps up rapids and over falls during the spawning migration were a source of inspiration to artists, poets and the common man alike. Atlantic salmon have long been considered to provide the ultimate freshwater angling contest, and many have been depicted

on magazine covers—cavorting in shimmering arcs at the end of a tapered flyline.

Its beauty, however, is paired with a fragility that caused it to become the first anadromous species to disappear in the wake of the industrialization of 19th century New England. Dependent upon the cold headwaters of rivers for reproduction, it could not survive the damming and pollution of the mainstems of its migratory routes. Textile and pulp mills, hydropower dams and urban effluents—each helped signal the end of the New England Atlantic salmon fishery more than a century ago.

Man has attempted repeatedly to restore and enhance populations of Atlantic salmon in New England during the past 100 years. Restoration efforts on the Connecticut and Merrimack Rivers, after producing modest successes in the late 1800s, were abandoned. Ever-increasing water pollution, the construction of additional dams, inadequate fish passage facilities, and over-fishing within the two rivers probably contributed in large measure to the failure. Restoration efforts in Maine, beginning in the latter part of the 19th century, had produced few positive results by the middle of the 20th. Salmon populations had reached an extremely low level in many streams. The spawning run in Maine's famed Penobscot River was nearly gone. By 1950, less than two percent of the original salmon habitat—estimated to have been 75,000 square kilometers—was accessible to salmon and only eight of the 43 rivers that once produced salmon contained reproducing remnants of once flourishing populations.

Maine, in 1947, formed the Atlantic Sea Run Salmon Commission (ASRSC) to intensify efforts to protect and enhance the dwindling salmon populations. Then, and for the next 20 years, the U.S. Fish and Wildlife Service's Atlantic salmon program consisted primarily of producing salmon at the Craig Brook National Fish Hatchery in East Orland, ME, from eggs provided by the ASRSC.

During the period there was some localized interest in salmon restoration in southern New England, but money was scarce and there were no fish stocks available to work with. Except for Maine, the Atlantic salmon had become extinct in New England.

Environmental By-product

In the mid-1960s, the environmental movement was beginning to peak and a series of events catapulted Atlantic salmon restoration to the fisheries management forefront. Water quality in major New England rivers improved as wastewater and sewage treatment increased. State resource agencies, reflecting mounting public concern, began flexing their muscles and called upon public utilities—owners of most of the mainstem dams blocking anadromous fish passage—to live up to Federal licensing requirements and provide fish passage over their dams.

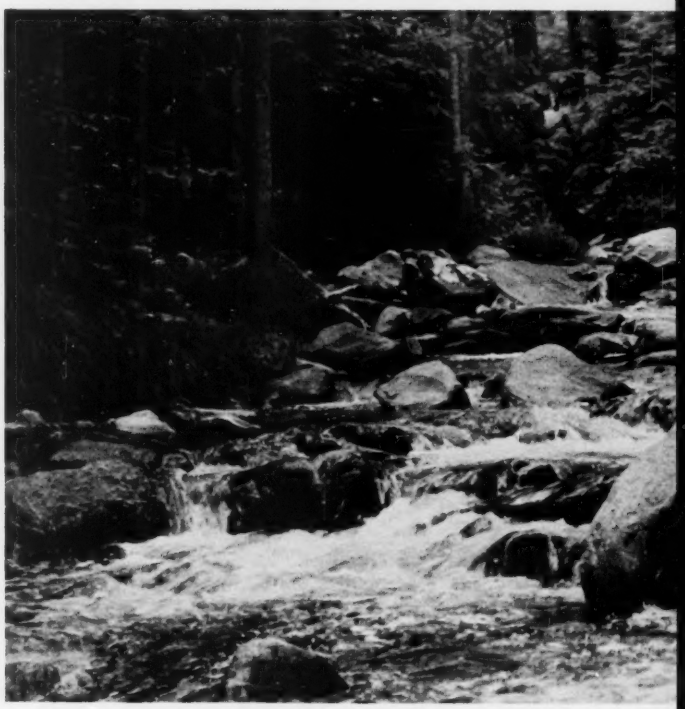
The Fish and Wildlife Service's salmon propagation program placed more emphasis on smolt production and less on fry and parr (a salmon that has not yet entered the ocean) for stocking. Controls were being applied and enforced over the high seas commercial salmon fishery. Increasing returns of adult spawners in Maine increased the egg supply for the propagation program.

Model River Program

In 1965, Congress passed the Anadromous Fish Conservation Act that provided Federal cost-sharing for restoration programs. This additional source of revenue enabled State agencies to more aggressively pursue Atlantic salmon restoration, and it may be the single most significant stimulus to the restoration of Atlantic salmon in the United States. Using these funds, Maine's ASRSC, the F&WS, and public utilities joined forces in initiating a Model River Program on the Penobscot River to demonstrate that salmon could be restored.

Fishways were constructed and smolt stocking was increased. While not a direct result of the Act, the Green Lake National Fish Hatchery was constructed in Ellsworth,

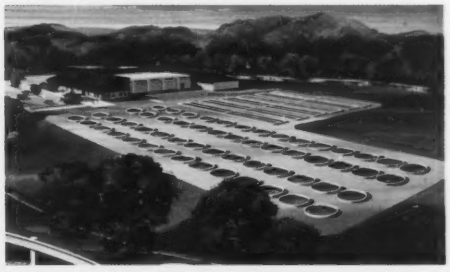
This New England headwater stream is typical of those used historically by the Atlantic Salmon as a reproduction and nursery habitat. (F&WS Photos)

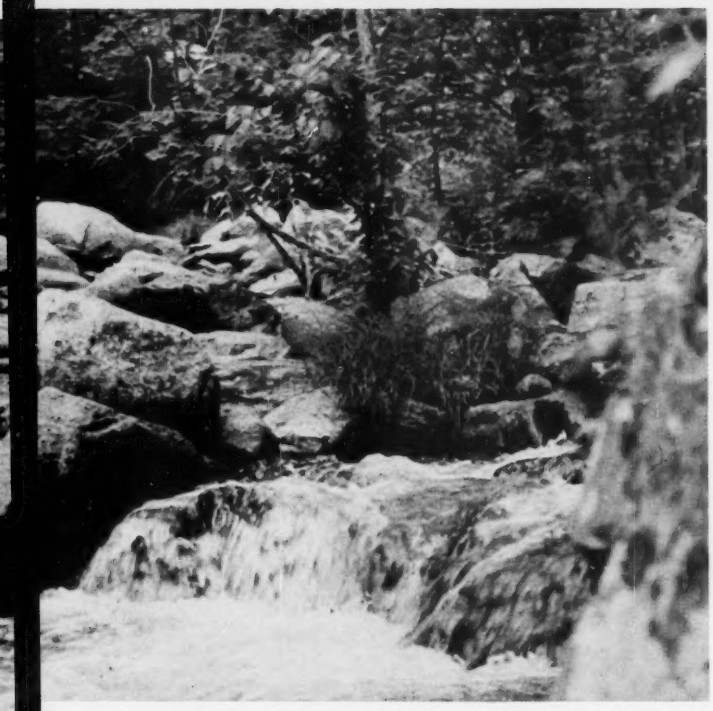


The Craig Brook National Fish Hatchery at East Orland, Maine, carried the entire burden during the first 20 years of the salmon restoration program.

This dam on the Merrimack River in Massachusetts is typical of the 19th century hydropower development that destroyed the native salmon runs.

An artist's conception of the White River National Fish Hatchery being built in Bethel, Vermont. It will produce 500,000 smolts for the Connecticut River annually when completed.





ME at this time, with the capability of tripling the salmon production of the Craig Brook facility.

The southern New England States joined in formal cooperatives with the F&WS and the National Marine Fisheries Service to restore shad and Atlantic salmon to the Connecticut and Merrimack Rivers. The U.S. supply of salmon eggs for restoration was limited to Maine and was barely adequate for the needs of Maine's rivers. The Connecticut and Merrimack Programs had to look to Canada for assistance.

The Canadian Government and the Provincial Government of Quebec, although hard pressed to rebuild some of its own salmon runs, generously offered support in the form of salmon eggs. In exchange, F&WS provided disease-free trout eggs and fingerlings to Canada. With agreement from the states involved, the Service converted several of its New England hatcheries from trout production to the production of salmon smolts. Construction of a 500,000 smolt capacity Federal salmon hatchery at Bethel, VT, was initiated.

The Program Today

The Service's relatively obscure one state/one hatchery salmon program of 1965 has grown to a top priority, five state/six hatchery program and involves three Fishery Assistance Field Stations. During the last decade, following the implementation of these programs, approximately 1,200,000 smolts and 400,000 fry and parr have been released into the Penobscot River; 630,000 smolts and 250,000 fry into the Connecticut River and 80,000 smolts and 300,000 fry into the Merrimack.

The adult returns from the earliest stockings were few, often less than 0.1 percent of the smolts released. Results, however, are improving with each year class as culture and stocking techniques improve and the salmon stocks used become better adapted to the more southerly river systems. Recent returns of hatchery smolts average about 0.3 to 0.5 percent and are improving—with about 1 percent of some lots returning as adults in Maine.

Returns to the Connecticut, near the southern boundary of the salmon's historic range, have been slow as would be expected when relying on salmon stock of distant northern origin. However, in only a few years, documented returns have grown from single digit numbers to approximately 70 adults in 1978. The first returning adults on the Merrimack are not expected until 1979, and it will probably be 1982 before significant returns develop. Observable returns to the Penobscot have grown from a few hundred at the start of the Model River Program to approximately 1,000 today. Knowledgeable biologists agree that this figure constitutes only about one-third of the actual run, as there are known escapement routes through the check stations. Conversely, the Connecticut count is considered valid. A new run of several hundred adults has been established in the Union River in Maine. Other Maine salmon rivers, the Denneys, Narraguagus, Machias, Pleasant and Sheepscot, have significant salmon runs that are essentially self-sufficient,

Sampling of juvenile salmon populations, such as this study on Vermont's White River, is part of a special effort underway to determine the potential of former nursery habitat to produce wild salmon today.

Figure 1

NEW ENGLAND ATLANTIC SALMON RESTORATION
A Multi State/Federal Cooperative Effort

Connecticut River Restoration

Connecticut River Policy & Technical Committee

- Vermont Fish & Game
- New Hampshire Fish & Game
- Mass. Wildlife Resources
- Mass. Marine Resources
- Conn. Dept. Envir. Protection
- U. S. F. & W. S.
- N. M. F. S.

Merrimack Basin Restoration

Maine Atlantic Salmon Research Committee

- Maine Wildlife Resources
- Maine Marine Resources
- Maine Atlantic Searun Salmon Commission
- University of Maine
- U. S. F. & W. S.

Maine Rivers Restoration

Merrimack River Policy & Technical Committee

- New Hampshire Fish & Game
- Mass. Wildlife Resources
- Mass. Marine Resources
- U. S. F. & W. S.
- N. M. F. S.

Outside Agencies

- N. E. R. B. C.
- U. S. A. - C. O. E.
- U. S. S. C. S.
- U. S. F. S.
- Environ. Canada

COMPREHENSIVE PLAN FOR THE RESTORATION OF ATLANTIC SALMON IN NEW ENGLAND
Lead Agency - U.S.F.&W.S.
Compl - 1980

Private Sector

- I. A. S. F.
- R. A. S. A.
- Conn. River Salmon Assoc.
- Conn. River Watershed Council
- Trout Unlimited
- + Others

although they are bolstered with occasional hatchery smolt replenishment.

Cooperative Structure

There are three programs (Fig. 1) comprising the overall effort for salmon restoration in New England. The Connecticut River and the Merrimack River Programs differ from the Maine effort, in that they are multi-state in scope (Fig. 2). Each program operates somewhat differently, but a common thread through them all is their cooperative, interagency nature. Neither solely state nor Federal, they are cooperative state/Federal alliances established by written Cooperative Agreements.

Policy decisions regarding the salmon program on the Connecticut, for example, are the responsibility of the directors of the fisheries agencies in the States of Connecticut, Massachusetts, New Hampshire, Vermont and the Northeast Regional Directors of the National Marine Fisheries Service and the F&WS. This group is advised by a technical committee composed of fisheries biologists and other staff individuals from the respective state and Federal agencies.

The Merrimack program has similar governing bodies; however, only two States—Massachusetts and New Hampshire—and the two Federal agencies are involved.

The salmon restoration program in Maine is the responsibility of the aforementioned Atlantic Sea Run Salmon Commission. This body is advised by a research committee having members from the F&WS, the Maine Department of Inland Fisheries and Game, the Maine

Department of Marine Resources, the University of Maine, and the ASRSC itself.

Federal Role

The overall goal of the F&WS for the Atlantic salmon is to restore, maintain, or enhance their populations in suitable areas of their historical habitat in the United States. The origin of the Federal role in restoration is rooted in the migratory behavior inherent in anadromous species.

Salmon move great distances even after entering fresh water. They pass through international and state waters, usually pursued by both commercial and sport fishermen. Tremendous management complexities are inevitable when a species travels from international jurisdiction to multi-state and, within a state, multi-agency jurisdiction—all the while the object of competitive user groups. When a state or group of states wishes to undertake the management of such a transient fishery

resource, involvement of the F&WS has proven to be an effective means of planning and coordinating the multi-jurisdictional management program.

The F&WS produces more than 90 percent of all Atlantic salmon being released in U.S. waters. More than 500,000 salmon presmolts are reared annually in five Federal fish hatcheries within the Northeast Region. Craig Brook has been in production, in varying degrees, since 1871, and currently produces about 170,000 smolts each year. The newest incubatory, Green Lake, is still not completed but is already hatching 275,000 salmon annually. When completed it will provide more than 500,000. Salmon from these two stations are destined primarily for the Penobscot and Union rivers within the State of Maine.

The recent conversion of hatcheries in Vermont and western Massachusetts from the production of legally catchable trout to Atlantic salmon enables the Service to produce more than 100,000 salmon smolts annually for the Connecticut River Restoration Program. The White River National Fish Hatchery, presently under construction at Bethel, VT, will shortly add its 500,000 annual smolt production to the Connecticut system.

The third, and newest, salmon restoration effort is in the Merrimack system, which received its first planting of 25,000 smolts in 1977. The Nashua National Fish Hatchery in New Hampshire has been converted from trout to salmon rearing, and is expected to produce 100,000 smolts annually for the Merrimack beginning in 1980.

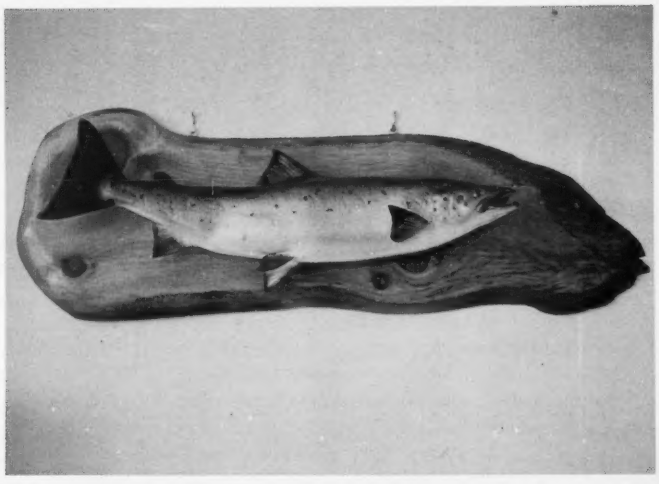
Several Fishery Assistance Stations are involved in the Anadromous Fish Program. Special studies are being conducted in the headwaters of the Connecticut and Merrimack River Basins by the Montpelier, VT and Laconia, NH Offices of Fishery Assistance to determine the capability of historical salmon nursery habitats to produce salmon today. Salmon are being fitted with miniature radio transmitters and are tracked on their migration to the sea to determine how these juveniles are affected by hydrodams and huge pump-storage intakes.

Technical assistance is provided to state agencies and utilities involved in the salmon restoration in such highly specialized areas as fishway design, culture, radio tracking and disease diagnostics. In biologically and

Figure 2.

Smolts are weighed at the North Attleboro (Mass.) National Fish Hatchery, prior to being released in the Merrimack. More than 50,000 salmon have been introduced into the Merrimack in the past two years.

A smolt is fitted with a miniature radio transmitter. Signals therefrom will help track the young salmon's migration downriver to the sea.



This mount is the first recovered adult salmon in the Connecticut River that can be directly attributed to the restoration program there. The fish was caught accidentally by commercial shad fishermen in 1975.

administratively complex multi-agency programs, such as the Connecticut and Merrimack, the vital role of coordination falls to the Service and is a prime function of field assistance offices in Massachusetts and New Hampshire.

Planning

For the Atlantic Salmon Plan to be a viable working document, the philosophies of *all* the participating agencies must be understood and incorporated. These philosophies can be defined in two principal ways:

- The development and maintenance of a salmon population entirely from hatchery production in order to provide specific levels of sport harvest.
- The development and maintenance of a salmon population with the principal objective of optimizing the wild smolt population.

The importance of these definitions lies in their differing impacts on Atlantic salmon hatchery needs and management.

The first definition requires total reliance on the hatchery and generates a management program that addresses only the sport fishery. Supply and demand become the pivotal considerations in this situation. Hatchery production needs based on specific adult population levels desired can be reasonably estimated for many of our rivers, and the actual adult needs are totally decisions of management.

This approach may not be considered by some as being truly "restoration," but it is the only possible approach in several historic salmon rivers and major tributaries. Man's modification of some of these streams is so extensive that natural reproduction is no longer possible. A smolt stocking program, however, could provide an adult salmon run to support a sport fishery. This worldview of salmon restoration is subordinate in priority to the restoration and maintenance of a reproducing wild population under the goal of the F&WS, but may be of a relatively high priority on a particular river to a state agency.

The second definition, in reality, will also require a continued reliance on the hatcheries, although to a lesser degree. The development and maintenance of spawning populations will require hatchery supplementation in most cases, primarily due to losses associated with hydropower development. Hatchery program needs can be estimated based on specific wild fish deficiencies. Management programs must be designed to protect a required minimum number of spawners.

This second approach to restoration is given high priority by the Service, and the Service's hatchery production and management investigations are aimed at developing and maintaining reproducing populations that can also provide sport fishing under the management of the appropriate state agency.

A plan for the restoration of Atlantic salmon in New England will address both philosophies of restoration and the strategies necessary to apply whichever approach is appropriate on a particular river. The Federal and the states' roles and priorities in pursuing these strategies may differ, and the greatest value of the plan may be the clear definition of the roles of various agencies as the rapidly growing Atlantic salmon restoration effort reaches maturity.

A melding of the two philosophies will be necessary in the Atlantic Salmon Plan. The F&WS believes strongly that its efforts should be toward restoration. This relates specifically to the second definition. It also realizes that sport fishing will be important. However, this recreational fishing should be provided by salmon not needed for spawning and the perpetuation of their kind.

Major Problems

There are three basic areas that present immediate problems to each of the three restoration programs which are being addressed by the current Federal/State cooperative programs:

- Brood stock development
- Fish passage at hydro-electric facilities
- Resident fresh water fisheries

A lack of suitable stocks from which eggs could be obtained has continually plagued the Connecticut and

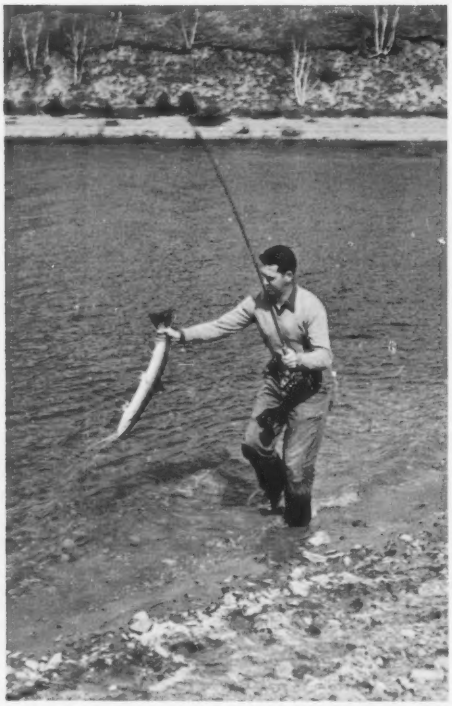
Merrimack River programs. This problem is not as critical to the program in Maine. The use of eggs from landlocked salmon fertilized by sea-run males is being experimented with in Vermont and New Hampshire. The Service is currently holding the progeny of sea-run fish in the hatchery to mature and use for brood stock until the Connecticut and Merrimack runs provide a sufficient egg supply. Both of these programs are still heavily dependent upon eggs provided by Canada. The Service feels that on the Connecticut, however, the light may be visible at the end of the tunnel for self-sufficiency in view of 1978's dramatic increase in adult returns.

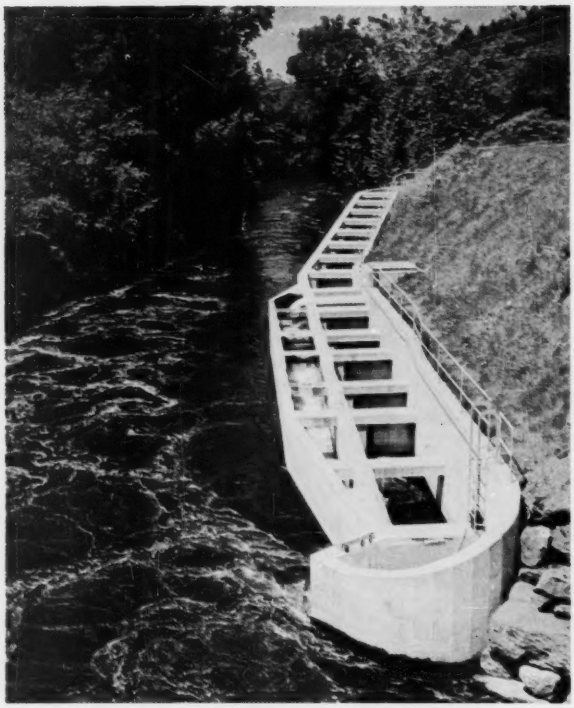
Fish passage must still be considered at possibly 100 obstructions. Downstream migrant losses at possibly 64 hydroelectric facilities must be considered. It has been estimated that perhaps half of the smolt population leaving the Merrimack headwaters are lost before reaching the ocean. The potential for rehabilitation of the old dams not now producing power increases with our increasing energy needs, and this problem may very well be magnified. Progress to date on the major mainstem barriers has been encouraging. The Penobscot is essentially open to salmon now and negotiations between the states and Connecticut River hydropower interests to provide a construction schedule for fishways on all the important mainstem barriers are nearly complete.

Atlantic Salmon smolts are hand stocked in the Merrimack by the Massachusetts Department of Fisheries, Wildlife and Recreational Vehicles.

This fish ladder, on the Rainbow Dam on Connecticut's Farmington River, symbolizes federal, state, and private landowner cooperation in restoring the wild salmon fishery. Using a trap constructed as an integral part of the fishway, this site provides for most of the adult return counts on the Connecticut.

An Atlantic Salmon sport fishery is now a reality on a growing number of New England rivers. This adult spawner was landed in Maine.

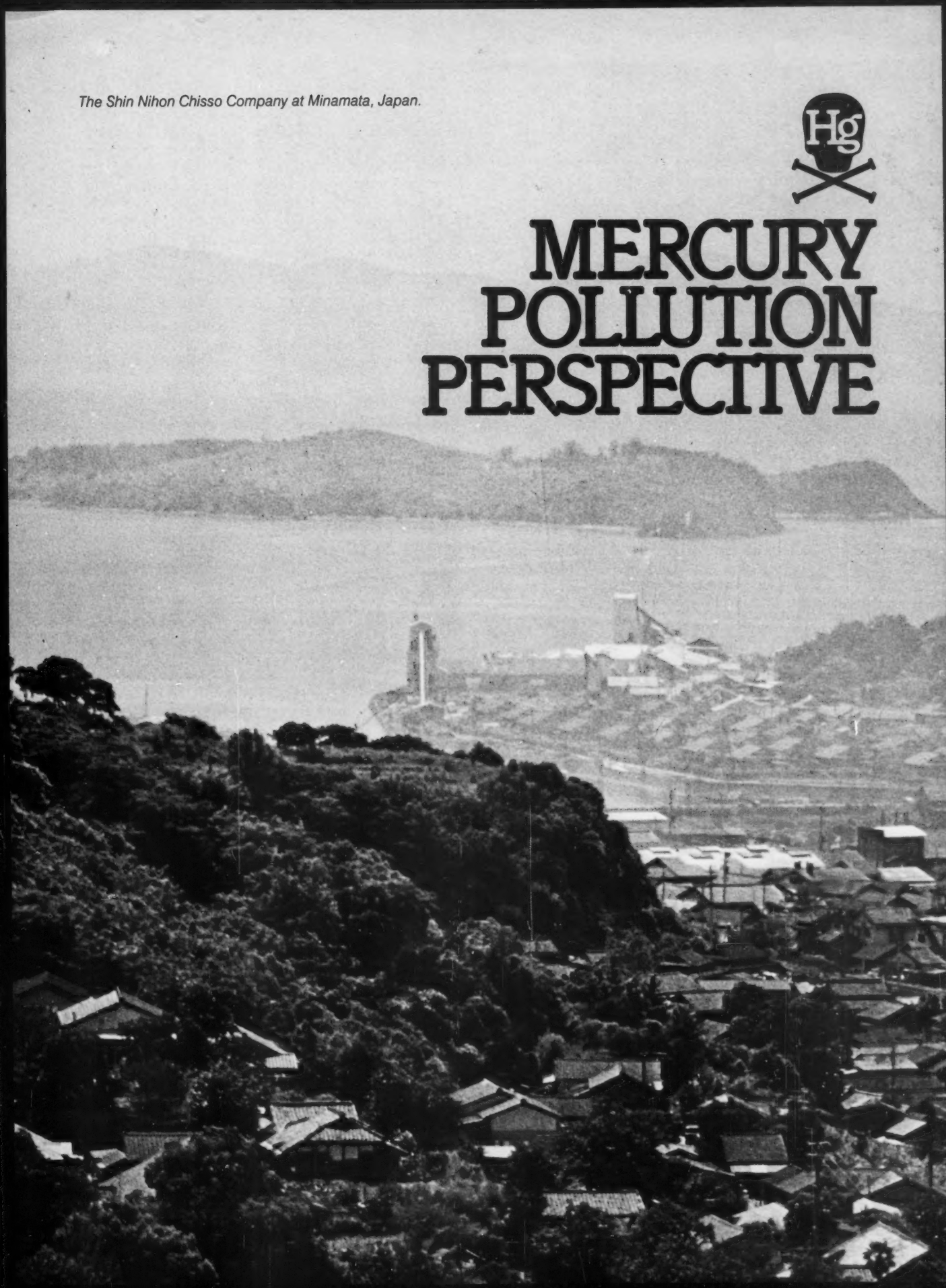




The Penobscot, Merrimack and Connecticut Rivers have a diverse resident fish fauna. The Penobscot has at least 38 species, the Merrimack 46, and the Connecticut 60. Potential salmon predators such as the northern pike, chain pickerel, smallmouth bass and the American eel abound in much of the waters. There are also areas having wild populations of rainbow, brown and brook trout that support significant sport fisheries. Additional areas support intensive sport fisheries for trout using put-grow-and-take programs. Whether or not a successful restoration of Atlantic salmon will have an impact on these fisheries or *vice versa* is still unknown.

Several successful restoration efforts for the Atlantic salmon were made during the latter part of the 19th century. These successes were short-lived as the technology of that day could not cope with the problems of access and pollution. Today, the same problems are with us, but we have the tools to attack them and the public commitment to use them.

The public interest in Atlantic salmon restoration transcends the species' value as a sport or even a commercial fish. The Atlantic salmon has become a piscatorial counterpart to the bison and the whooping crane. It has become a symbol for cleaner rivers and a rallying call for repair of past damages. It represents a part of our heritage almost lost. The restoration of Atlantic salmon to their ancestral homes is to many a signal that the environment is getting better and that past wrongs can be righted. The Atlantic has returned. ■



The Shin Nihon Chisso Company at Minamata, Japan.

MERCURY POLLUTION PERSPECTIVE

by **Patricia A. and Frank M. D'Itri**

When the cats began to dance and then flung themselves into the sea, the warning went unheeded. Even when birds fell out of the sky, the poor fishermen of Minamata, Japan, did not become alarmed. Later, when they and members of their families became numb, began to stagger as they walked, and found their vision constricted to narrow tunnels, their first reaction was fear that they had contracted a social disease. Thus they hid their illness until their memories degenerated and their bodies stiffened into contorted poses. Some lapsed into comas and died. Finally, in 1956, as more children were born crippled and retarded, mothers began to take them to the hospital at the nearby Shin Nihon Chisso Chemical Company. Physicians surveyed the increasing number of victims and decided an epidemic was underway. They called in researchers from Kumamoto University to help find the cause. After studying the water, living conditions, and other possibilities, the researchers finally concluded that Minamata Disease was really poisoning caused by eating fish contaminated with methylmercury that had been discharged into Minamata Bay and the Minamata River by the Chisso Company.

Elemental mercury is of natural origin and has been known since antiquity, but many of its organic compounds, which are deadly neurotoxins, are the products of modern industrial processes. Industrial discharges of tons of elemental mercury and the misuse or discharge of its compounds have been responsible for several major disasters in which thousands of human beings have been killed or crippled (see Table 1). The danger is insidious. Damage to the environment is not readily apparent, and exposure may come from seemingly harmless sources such as eating healthy fish taken from sparkling, clear waters. At Minamata, researchers learned that, unlike inorganic mercury, alkylmercurials such as methylmercury accumulate slowly in the human body and cause permanent damage. They pass through the blood-brain barrier to destroy brain cells and attack the central nervous system. As brain cells are lost, middle-aged people show signs of aging that make them resemble their elders; among congenital victims of Minamata Disease sometimes subnormal mental capacity is the only symptom. While the brain and central nervous system are most susceptible to destruction by methylmercury, an accompanying general decline in the body's efficiency makes it more vulnerable to infections and degenerative diseases such as cancer, arteriosclerosis, and diabetes that often cause deaths attributed to old age. Methylmercury also crosses the placental barrier to attack the fetus.

Drs. Patricia and Frank D'Itri teach at Michigan State University in East Lansing. They are the authors of *Mercury Contamination: A Human Tragedy* (New York, Wiley-Interscience, 1977). Except as noted, photographs are by Frank D'Itri.

Disturbing Discoveries

At Minamata, the symptoms of methylmercury poisoning ranged from subchronic to acute and generally occurred over a range of a few weeks to several years. The duration of the latency period depended on the intake of fish from Minamata Bay and the individual's susceptability, both of which varied widely. However, by 1960 the poisoning had been traced to fish that had concentrated methylmercury discharged as a by-product of the manufacture of acetaldehyde, a plastics intermediate. Methylmercury was not even recognized as part of the manufacturing waste of the Shin Nihon Chisso Chemical Company until local families became ill from eating the contaminated fish. The levels in fish, it was discovered, were 10 to 30 thousand times greater than those in the water. Fish absorbed the chemical from their food and from water passing across their gills.

The Kenora, Ontario, area suffered a six to ten million dollar loss in 1970 when news of mercury contamination kept tourists away.

Poisoning symptoms similar to those seen at Minamata were observed in Iraq in 1971 after seed grain treated with a methylmercury fungicide was distributed to peasants. The grain was intended only for planting. However, as in other

Table 1. Summary of Epidemics Resulting from Methylmercury Contaminated Food.

Year	Location	Source of Methylmercury	Food Contaminated	Deaths	Afflicted
1953-1960	Minamata, Japan	Industrial Discharge	Seafood	121	798*
1965	Niigata, Japan	Industrial Discharge	Seafood	6	47
1956	Iraq	Seed Dressings	Grain	70	>200
1960	Iraq	Seed Dressings	Grain	200	>1000
1961	West Pakistan	Seed Dressings	Grain	10	100
1965	Guatemala	Seed Dressings	Grain	20	45
1967	Ghana	Seed Dressings	Grain	20	144
1969	Mexico	Seed Dressings	Grain	2	4
1969	United States	Seed Dressings	Pork	—	4
1971-1972	Iraq	Seed Dressings	Grain	>459	>6530**

* More than 3000 await verification.
** Unofficial sources have reported as many as 4,000 dead and 40,000 afflicted.

White Dog Reserve is located on a remote road amid the beautiful Ontario scenery. Ontario Public Interest Research Group (OPIRG)

epidemics in Iraq, Guatemala, and Pakistan, the poverty-stricken families ground the seed grain into flour to make bread. The latency period was just long enough to convince people that government warnings against eating the grain were false. Then, within a few weeks, in all provinces of Iraq, up to sixty thousand people were poisoned. The hospitals were quickly swamped, and many victims did not have access to them. The government officially acknowledged that 6,530 were hospitalized and 459 died; tourists reported that thousands suffered brain damage, blindness and paralysis.

This acute epidemic enabled researchers to determine clearly that the onset of numbness of the fingers and toes could be expected after ingestion of approximately 25 mg of methylmercury. The staggering gait usually began at about 55 mg, difficulty speaking at 90 mg, deafness at 170 mg, and death when the body burden of methylmercury reached approximately 200 mg. As at Minamata, the damage was permanent, but recovery by compensating cells enabled many of the victims to learn to walk, see, and hear again. How much the aging process was advanced by the early use of these compensatory cells cannot be determined for many years.

The epidemics in Japan and Iraq were both caused by the direct introduction of methylmercury into the environment. Another way methylmercury reaches the environment and the human food chain was discovered in the early 1960s. It had been assumed that the liquid metal remained in its original form after being discharged into waterways, even though chemical reactions and biological conversions were known to occur in other circumstances. Before methylmercury was found in the chemical waste discharges at Minamata, however, the possibility was raised that elemental mercury discharged from the factory might have been naturally methylated in the bay. This theory remained unproved until Swedish researchers discovered exceptionally high levels of methylmercury—1 to 9.8 ppm—in fish taken downstream from wood pulp mills and chloralkali plants that discharged only elemental or aryl mercury into the waterways.

When natural waterways were simulated in laboratory experiments in which only elemental mercury or its inorganic compounds were added to the water, microbes were able to alter the mercury in several ways. Some microbes absorb mercury on the outside of their cell walls, where it converts directly into a vapor. Others, such as *Escherichia coli,* absorb it into their systems. There mercuric ion may combine with cytoplasm, degrade, and form another compound or the volatile elemental form. This, in turn, can be methylated and discharged into the waterway to be concentrated by fish. Methylation can be carried out by microbes that live in any waterway, even anaerobic sewage lagoons. Oxygen is not necessary. Nor is life itself; methylcobalamin reacts with mercuric ion to produce methylmercury. Methylcobalamin is widely distributed not only in microorganisms but in other tissues, and methylation has been induced in homogenates of calves' livers, blood plasma, and the kidneys of hogs. Demethylation is being carried out at the same time, but this does not deter the concentration of large quantities of methylmercury in fish.

That mercury could be methylated in the waterways and concentrated in fish in quantities sufficient to pose a health hazard were two of the major scientific discoveries since World War II. Unfortunately, over the previous six centuries thousands of tons of the element had been mined, most

At Barney Lamm's Ball Lake Lodge, the canoes have been stacked on shore since 1969.

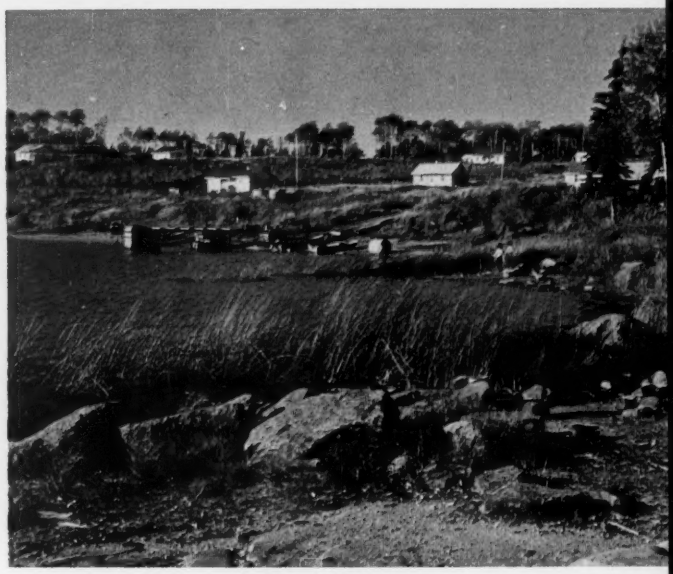
notably from a few rich deposits in Spain, Italy, Yugoslavia, and California. Its versatility in industry, agriculture and medicine has resulted in the application and discharge of vast quantities into the environment. As a result, in California fish now have elevated mercury levels because tons of the element were lost as miners reclaimed gold by means of mercury amalgamation in the gold rush of 1849 and after.

Uses of Mercury

Elemental mercury and its inorganic compounds are most familiar in thermometers and barometers and as the red "antiseptic" applied to childhood cuts and scrapes. Workers who manufacture these products, mine and refine mercury, or amalgamate it with gold, aluminum or zinc (and in the past even dentists who filled teeth with mercury amalgams) can develop loose teeth, fatigue, and nervous disorders from inhaling mercury vapors. These symptoms are generally reversible, however, so inorganic mercury poisoning can be controlled by rotating workers away from exposure or by taking safety and sanitary precautions.

Some applications of mercury have decreased or become obsolete. Mirrors are no longer "silvered" with mercury, and gilding is rare, since few members of royalty are now building elaborate palaces. The fur in felt hats is no longer carrotted with mercuric nitrate, thus eliminating a source of poisoning that caused thousands of cases in the past—including that of Lewis Carroll's Mad Hatter. Fingerprints are no longer dusted with "grey powder," and annual peacetime demand for fulminate of mercury, used to make detonators and blasting caps, has been one-tenth of World War II levels.

While some uses of mercury have declined in importance, the number of industrial applications nevertheless continues to increase. Because of its physical characteristics, including its density, liquidity at room temperature, and the ease with which it can be frozen or vaporized, mercury serves a wide variety of functions—for example, in the manufacture of bowling balls and jewelry, in gyroscopes that stabilize spacecraft in flight, in non-marine paints, in flotation platforms for telescopes, in fuel cells, for cooling nuclear reactors and shielding atomic devices, as seed dressings, and in separating a lithium isotope used to make H-bombs. Compounds of



Grassy Narrows is a modern but isolated settlement on the English River where approximately 500 Native People live. OPIRG

mercury are catalysts in the manufacture of plastics, including polyvinyl chloride, the widely used imitator of wood, leather, and chrome. Currently, manufacture of electrical and mechanical equipment, including dry cells, mercury switches, and mercury vapor lamps, is the major U.S. use of mercury, consuming over 2,000,000 pounds in 1977.

As uses of mercury proliferated during the past several decades, both U.S. consumption and price both rose. Then, beginning in 1970, the discovery of elevated mercury levels in North American fish led to reduced consumption and price, at least temporarily (see Figure 1). According to a U.S. Environmental Protection Agency study, in 1973 U.S. consumption for industrial, commercial, and consumer uses amounted to an estimated 4.1 million pounds. In the same year, losses to the environment attributable to human activity, including mining and coal burning, were an estimated 3.4 million pounds.

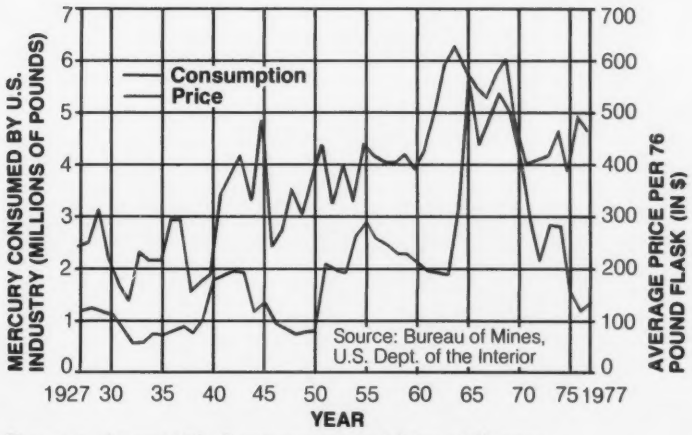

MERCURY CONSUMED BY U.S. INDUSTRY (MILLIONS OF POUNDS)
AVERAGE PRICE PER 76 POUND FLASK (IN $)
Consumption
Price
Source: Bureau of Mines, U.S. Dept. of the Interior
YEAR
1927 30 35 40 45 50 55 60 65 70 75 1977
0 1 2 3 4 5 6 7
0 100 200 300 400 500 600 700

Figure 1. Annual U.S. Consumption and Price of Mercury, 1927-1977

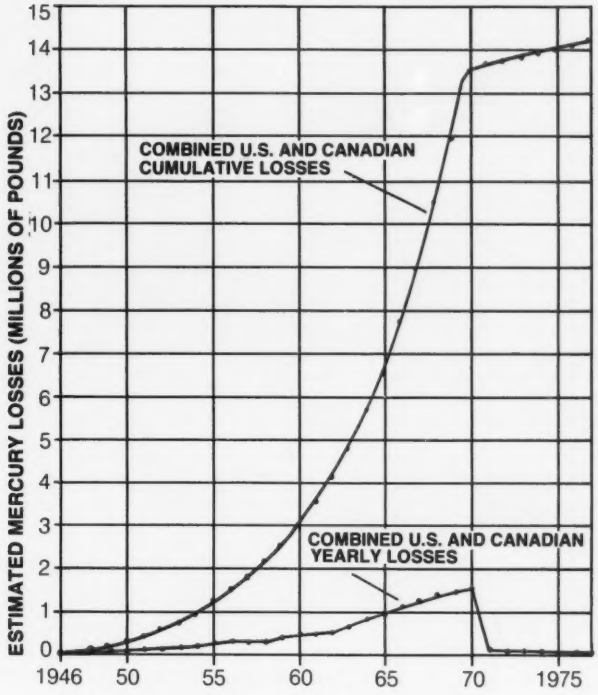

ESTIMATED MERCURY LOSSES (MILLIONS OF POUNDS)
COMBINED U.S. AND CANADIAN CUMULATIVE LOSSES
COMBINED U.S. AND CANADIAN YEARLY LOSSES
1946 50 55 60 65 70 1975
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Figure 2. Estimated Yearly and Cumulative Losses of Mercury to the Environment by the U.S. and Canadian Chloralkali Industries since 1946.

Note: Estimates assume 0.5 pound of mercury released per ton of chlorine produced for the years 1946 to 1970, and 0.03 per ton during the years 1971 to 1977. Based on Canadian chlorine production data from Statistics Canada and U.S. production data from the Chlorine Institute.

A major consumer of mercury and source of mercury pollution has been the chloralkali industry, which produces both chlorine and caustic soda. Mercury is used in only one of the two common methods of producing chlorine and caustic soda, but the demand for purer caustic soda that arose after World War II led to an increasing utilization of mercury cells—from 4 percent in 1946 to 30 percent in 1969 in the United States and 60 percent in Canada in 1972. Although new cells generally require less mercury than older models, losses of 0.5 pound of mercury per ton of chlorine produced were considered average in 1970. Since 1971, the industry gradually has reversed the trend toward mercury cell production, but between 1946 and 1977 over 14 million pounds of mercury were discharged by the U.S. and Canadian chloralkali industries (see Figure 2).

As one example, when Dow Chemical officials began to monitor discharges from the mercury cells at Sarnia, Ontario, in 1969, a five-mile long layer of sediment containing up to 1700 ppm of mercury already coated the bottom of the St. Clair River, and much of the element had been washed downstream to Lake St. Clair and then into Lake Erie. At that time the Sarnia plant averaged daily losses of about 70 pounds in a range from 47 to 195 pounds. Between 1950 and 1970 losses averaged 30 pounds a day with a maximum of 200 pounds on occasion. Similarly, high mercury concentrations—up to 1800 ppm—were measured in sediments near a chloralkali plant in Saskatoon, Saskatchewan.

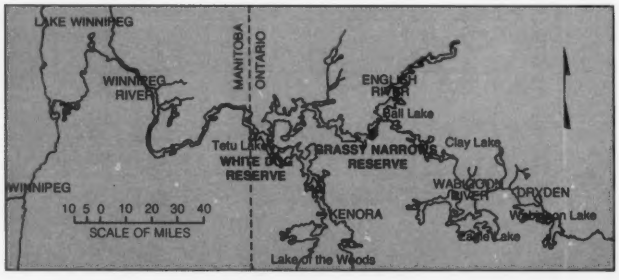
Mercury Contamination—Results and Reactions

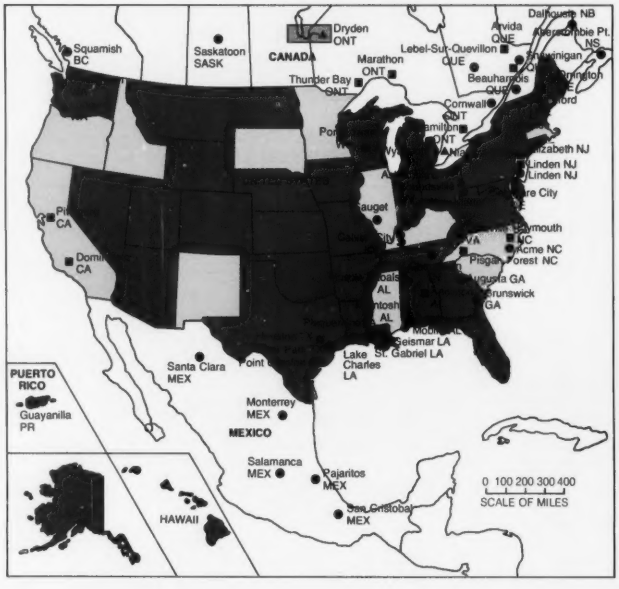
Excess mercury in fish was first discovered in Canadian waterways in 1969. The Canadian Federal Department of Fisheries and Forestry embargoed commercial fishing catches from Lake Winnipeg, Cedar Lake, the Saskatchewan River, and the Red River in Manitoba, and the government set a temporary 0.5 ppm "action level," decreeing that all fish that exceeded it were unsafe for human consumption. Initially, more than a million pounds of fish were confiscated. When a system of testing was established so safe catches could be sold, commercial fishermen were compensated for fish that were destroyed.

Mercury-contaminated fish were subsequently discovered in the waterways of Ontario and Quebec provinces, where

Figure 3. Current Status of Sport and Commercial Fisheries in the United States with Respect to Mercury Pollution, June, 1977, and Mercury Cell Chloralkali Facilities in North America, January, 1978, with an Exploded View of the Wabigoon-English River System

Source: State health and/or natural resources departments; the Chlorine Institute.





Legend

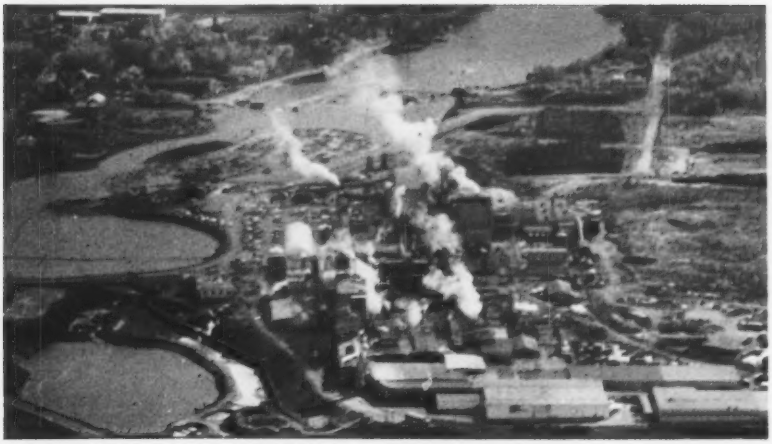
- ● Facilities operating mercury cells
- ▲ Operating facilities that have converted from mercury to nonmercury cells
- ■ Facilities that operated mercury cells but are now closed
- ■ States where closures of sport or commercial fisheries and health warnings are in effect
- ■ States with current health warnings about the consequences of eating mercury-contaminated fish or other seafood from selected watercourses in the state
- ■ States that have reopened sport or commercial fisheries or rescinded health warnings issued since 1970
- ■ States that report no closures of sport or commercial fisheries and no health warnings about mercury pollution since 1970

two-thirds of the Canadian chloralkali plants were located. (Many of them were on waterways that bordered the United States, so contamination affected fish taken by both countries. See Figure 3.) In Ontario six mercury cell plants replaced an average of 44,000 pounds of the element per year, and eight of the approximately 40 pulp and paper mills used mercury-based slimicides—fewer than in earlier years because of a U.S. ban on mercury in paper products used to package human foods. Nonetheless, in 1970 provincial officials estimated that Ontario's watercourses could be receiving from 26,000 to 104,000 pounds of mercury per year from these two sources alone. Obviously, large deposits of mercury in the waterways were being methylated and concentrated by fish.

Until 1969 both the United States and Canada had zero tolerance levels for mercury in food. The United States Food and Drug Administration (FDA) had ruled that mercury was an unintentional food additive. If the laws were strictly followed, then, all fish with any mercury residues—in other words, all fish—could have been seized. Instead, the United States quickly followed Canada's example and adopted an interim 0.5 ppm action guideline. The danger was played down by equating 0.5 ppm to the ratio of half a bottle of vermouth in a martini containing a million bottles of gin. By the same token, however, only half a pound of methylmercury could contaminate one million pounds of fish to the FDA action level.

Fishing was banned initially in lakes and streams where fish consistently registered above the 0.5 ppm action guideline. Both the United States and Canada quickly lifted the fishing ban, however, but advised people to limit their fish consumption. The rationale for this compromise was, first, that fish from Lake St. Clair averaged about 2.5 ppm, only one-tenth the average of contaminated fish at Minamata, and, second, that most Americans consume less fish than the Japanese do. The Canadians offered a similar justification, using average consumption figures rather than taking into account the dietary habits of minorities. However, an estimated 0.1 percent of the U.S. population, some 200,000 persons, eat substantially more than average quantities of fish because of choice, opportunity, or necessity. Similarly, in Canada substantially more than average quantities of fish are

The Dryden Chemical Company, Dryden, Ontario.



A fisherman from the USA prepares a shore lunch of fresh fish taken from Clay Lake, a few miles downstream from Dryden, Ontario.

consumed by some groups of Native People: the Walpoles who live near the St. Clair River, the Crees in northwestern Quebec, and the Ojibways who live at White Dog and Grassy Narrows Reserves on the highly contaminated Wabigoon-English River System.

The Native People in Northwestern Ontario

The Dryden Chemical Company of Dryden, Ontario, produced approximately 8,000 tons of chlorine per year and replenished its mercury cells with from 700 to 12,000 pounds of mercury annually between 1962 and 1975, when the cells were dismantled. By then deposits of the element lodged in the bed of the Wabigoon-English River System perhaps had already dealt the final blow to the traditional way of life for Native People in that area.

When the "Fish for Fun" policy was originally announced in the spring of 1970, camp owners on the Wabigoon-English River System were informed that warning signs picturing a frying pan with a fish dramatically crossed with a big red X would be displayed at public fishing sites. Since fish could be caught but not eaten, the owners wondered if fishermen would be willing to pay to fly to the remote fishing camps where the shore lunch had become a local tradition. The Indian guides would pull the boat up on shore and fillet the morning's catch to be eaten with cans of beans and spaghetti. The freshly caught fish fried over an open fire were the highlight of the fishing trip. Not surprisingly, many guests were suspicious of fish that were flown in for lunch if they could not eat those that were caught locally, and the tourist business fell into a sharp decline.

The largest fly-in fishing camp, Barney Lamm's Ball Lake Lodge, closed amid announcements that guests would be moved to uncontaminated waters for the season. (At that time local politicians talked of dredging to remove the mercury by the following year.) The Kenora, Ontario, area suffered a 25 percent economic loss—six to ten million dollars—because of mercury pollution. Since then camp owners who wanted to stay in business have generally rebuilt the tourists' confidence in local fishing by playing down the importance of mercury contamination and blaming the dismal 1970 season on bad publicity generated by Barney Lamm. The closing of his lodge is now blamed variously on a lack of business acumen, competition, or anything else that will dissuade tourists from concluding that mercury contamination could pose a health hazard for them. In fact, while methylmercury levels in the brain may continue to rise between one annual fishing trip and another, this short exposure is not likely to do much damage by itself. However, if reinforced with additional methylmercury concentrated during the year, tourists may place themselves at risk. The fish in the Wabigoon-English River System, although they appear healthy, have tested the highest in methylmercury concentration of any freshwater fish in the world.

Tourists can fly into the area, eat their shore lunches, and leave. The Native People who guide them to the fishing spots and share the shore lunch, however, have been faced with the choice of pretending mercury contamination did not exist or

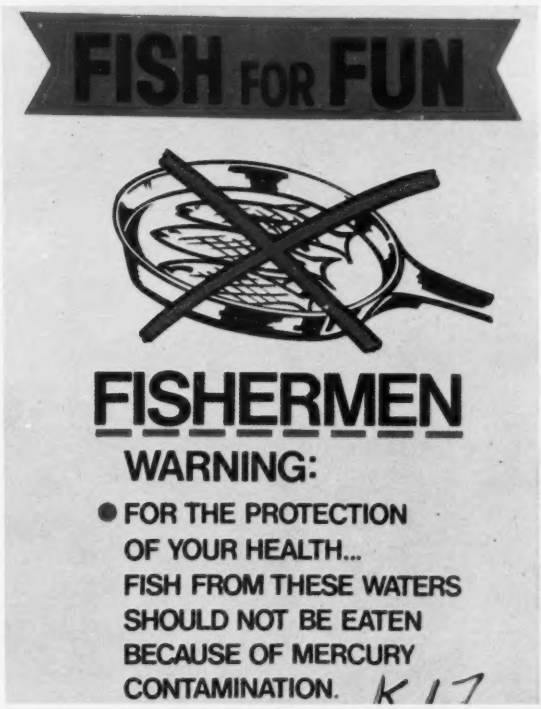
Members of the bands at Grassy Narrows and White Dog gather around the tribal drum during a protest against mercury contamination held at a government building in Toronto. OPIRG

losing their jobs as guides. When Ball Lake Lodge closed and commercial fishing was banned, 80 percent of the men from Grassy Narrows Reserve were unemployed. Left with welfare subsidies and a declining number of animals to hunt and trap, they turned to alcohol, and violence began to take an increasing toll of the community. In recent years suicide, murder, drinking methyl alcohol, and accidents such as being hit by trains have claimed many lives at Grassy Narrows and White Dog Reserves. Even fishing to increase the food supply is, of course, risky due to the elevated mercury levels.

Whether methylmercury has directly affected the health of the Native People is still disputed, but evidence is accumulating. At Minamata cats showed symptoms of poisoning earlier than people because they are more sensitive to methylmercury and eat more fish relative to their body weight. In federal laboratories at Ottawa, Canadian cats developed methylmercury poisoning after being fed a balanced diet containing a portion of contaminated fish from the Wabigoon-English River System. The disease was confirmed at autopsy. In 1975 a cat taken from White Dog Reserve exhibited clearly defined symptoms of methylmercury poisoning that also were confirmed at autopsy. A visiting Japanese physician, Dr. Masazumi Harada, has reported mercury poisoning symptoms in Native People, who described their numb fingertips, tremors, and tunnel vision. Recently, Canadian physicians have also noted evidence of unusual health problems. Some Indians have from 40 to 150 times more mercury in their blood than the average Canadian—levels that substantially exceed those at which neurological damage is known to begin.

What is to be done? To date the federal Canadian government has essentially declared that mercury contamination is a provincial problem. Federal officials acknowledge, however, that the central government has the authority to turn the Wabigoon-English River System into a national park. The Native People would thus be compensated for their land, but they fear being displaced again, as previously their ancient reserves were moved to accommodate the advent of the White Man's civilization: to White Dog to make way for a hydroelectric plant at One Man Lake, and to Grassy Narrows to locate the Hudson's Bay store on a more accessible road.

A sign posted by the Ontario Provincial Government in 1971 to warn tourists against eating mercury-contaminated fish. These signs quickly disappeared and are now collector's items.



Since 1970, the Ontario Provincial Mercury Task Force has provided the Indians with adult education classes so they can understand the mercury hazard, and electricity was installed at Grassy Narrows Reserve several years ago so that fish from uncontaminated waters could be brought in. However, the frozen fish were unpopular, and many fish spoiled when the freezer was vandalized in the spring of 1976. By then the gap between prices and welfare payments had widened, and the people acknowledged that they still ate contaminated fish when their welfare money ran out. Thus, where poverty prevails people continue to place themselves in jeopardy. In Ontario, at Minamata, and elsewhere around the world, those most immediately at risk from industrial contamination are also those least likely to have the political and economic clout to alter their situation. ■

Events, Deeds & Deliberations

Perched on a ladder, a volunteer checks a wooden nesting box for evidence of use. J. F. Gore

Students at Carlyle High School assemble a future home for wood ducks. J. F. Gore

Volunteers Help Corps Study Ducks

by **James F. Gore**

Balancing on a ladder in a rowboat is nobody's idea of good seamanship, but some southern Illinois sportsmen have been willing to assume that precarious position to help the U.S. Army Corps of Engineers study and improve the habitat for wood ducks at the Corps' Carlyle Lake. In fact, local volunteers, who have built nest boxes, fastened them to trees, and checked them annually, have made possible a five-year study of the response of wood ducks to nest boxes in an area that lacks natural nesting sites.

Wood ducks nest in cavities in trees—cavities formed when limbs drop from large trees, and insects and rot create hollows in the trunks. When Lake Carlyle was filled in 1967, water flooded trees surrounding a small area known locally as Speaker Lake. The trunks of most of the dead trees are less than ten inches in diameter—too small for natural wood duck nesting sites—so, as part of its development of a master plan for land use and recreation at the lake, the Corps decided to study whether wood ducks could be lured to nest in the Speaker Lake area in artificial nest boxes.

Lacking the people to build, install, and inspect the boxes, and looking for ways to get to the area's communities involved in their lake project, the Corps' St. Louis District enlisted the help of local groups. A sophomore industrial arts class at Carlyle High School and Migratory Waterfowl Hunters, Inc., a sportsmen's group from Alton, Illinois, built nest boxes. The latter group has put up over 1,000 nest boxes, mostly on Corps lands along the Mississippi River and at Carlyle and Shelbyville Lakes. Using plans and materials supplied by the Corps, the industrial arts class constructed wooden boxes; the sportsmen's group, using their own materials, built metal ones. In March, 1974, members of the Mississippi Valley Duck Hunters of Beltsville, Illinois, ventured into Speaker Lake in their boats, propped their ladders against the dead trees, and attached 83 nest boxes to the trunks about three meters above what would be the summer water level. The club members have returned every July since then to inspect the boxes for evidence of use—thus contributing to the research—and to maintain them. They remove old nests, see that the boxes are secure, and place sawdust on the floor of each box for the next season.

Observations of breeding pairs of ducks and evidence from inspection of nest boxes show that the boxes do, indeed, bring wood ducks to the area. What is more, the research shows what kind of habitat wood ducks prefer. This information will help wildlife biologists enhance the environment for these birds in the future. In 1973, the year before the boxes were put up, three inspection trips found only two pairs of ducks in mid-March, one in mid-April, and none in mid-May. The next year only one pair of birds was observed at approximately the time the boxes were installed. But in April and May, four pairs were seen on each inspection. In following years the number of breeding pairs counted rose, reaching a peak in 1976 of 19 pairs seen in March, 10 in April, and 15 in May. Numbers were slightly lower in 1977.

The July nest box inspections yielded corroborating evidence. In 1974, nests were found in 5 percent of the boxes. In 1977, 33 percent had clearly been used.

The wood ducks showed a preference for wooden boxes over metal ones and for boxes located adjacent to open water over those back in the trees. Over the four years boxes have been available, wooden box use was 38 percent

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Mr. Gore is a wildlife biologist with the St. Louis District, U.S. Army Corps of Engineers. He supervised the study he reports here.

while metal box use was 16 percent. Some researchers have recommended metal boxes because they are less vulnerable to predation by squirrels. Squirrels apparently did enter some of the wooden boxes in this study, but it is clear that, to attract wood ducks, wooden boxes are preferable. Boxes adjacent to open water were used 38 percent of the time, compared to 16 percent for boxes placed back in the trees. A hen sitting on the open water may be able to see the boxes at the lake's edge more easily, which could account for the difference in use rates. Also, boxes at the lake's edge may be easier to enter than boxes surrounded on all sides by trees.

Observations of nesting pairs and evidence of box use declined in 1977, but this may not have been due to specific conditions at Speaker Lake. Generally, wood duck populations in southern Illinois apparently declined between 1976 and 1977, possibly because of poor overall nesting success in 1976 or increased hunting in the 1976-77 season. ■

A male wood duck, one of the most colorful of waterfowl.
U.S. Fish & Wildlife Service

Water Quality Short of Goal

Although water quality throughout the United States is improving, the Annual Report of the Council on Environmental Quality predicts that it will not be totally "fishable and swimmable" by the legislated 1983 deadline.

While noting 50 polluted bodies of water nationwide that have greatly improved since the 1960s, the Council warns of emerging problems that will require close surveillance and control. Increasing coal usage is one example—with its concomitant danger of acid rain and the potential for planetary temperature increase.

The report also addresses a probable relationship between soft water consumption and the incidence of heart disease. Charts show that the Southwest, a hard water area, has a markedly lower heart disease rate than the Southeast, where soft water prevails. ■

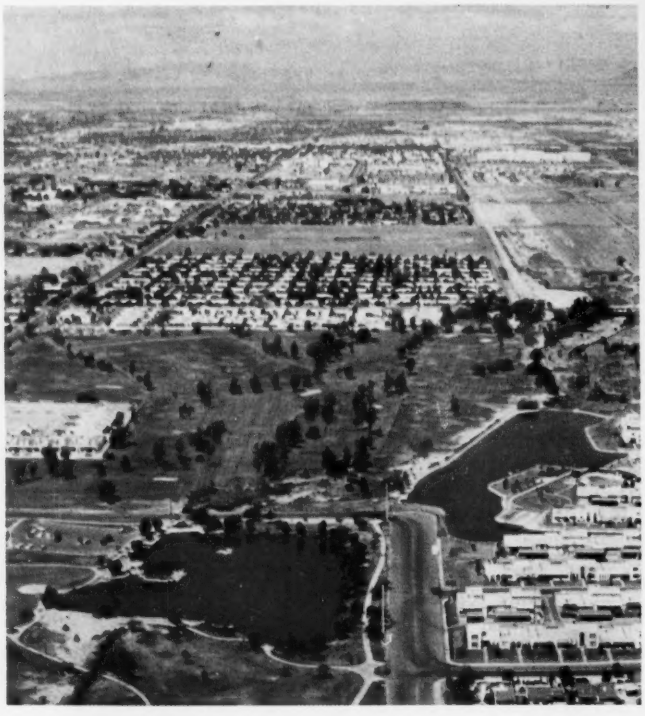
Flood Control with Grass

For flood control in arid urban areas, the engineer has traditionally relied on concrete. But a U.S. Army Corps of Engineers' project in Scottsdale, Arizona, is utilizing quite a different means of flood control—grass.

Although Indian Bend Wash in Scottsdale is usually a dry stream bed, heavy rainfalls—usually from short thunderstorms—have sent water over its banks 15 times in the last 50 years. In the early 1960s, Maricopa County, Arizona, appealed to Congress for help, and in 1965 Congress authorized the Corps to construct a flood control project for the wash. The Corps' first plan was conventional: a concrete channel running 4½ miles through Scottsdale, then through a corner of Tempe to the Salt River. In a desert urban area, a concrete channel has several advantages. Dry, dusty soil erodes rapidly under the pressure of heavy flows of water and so stream beds cannot contain or control flood waters. Obviously, concrete does not erode. Furthermore, building a concrete channel requires minimal land aquisition, an advantage since the cost of land is often a major consideration in designing an urban project.

Despite the engineering and cost advantages of a concrete channel, people in Scottsdale objected to the original plan. Some feared that a concrete channel running the length of the city would divide the community psychologically as well as physically. Others objected for reasons of aesthetics. Looking for alternatives to concrete, the city hired consultants who, in 1967, proposed a greenbelt floodway—a strip of undeveloped land along the banks of the wash that would contain flood waters. Then,

The Indian Bend Wash project has created a green oasis in the midst of a desert urban area.



working together, the Corps, the city, and the Maricopa County Flood Control District came up with a plan that expanded upon the consultants' idea. For flood control it combined the greenbelt through Scottsdale, 600 to 1,000 feet wide, with an inlet structure above the greenbelt, some levees, a system of concrete side channels, an outlet, and a revetted, earth-bottomed outlet channel through Tempe (in an industrial part of the city where there were no aesthetic objections). But flood waters coursing through the greenbelt could quickly erode the fragile soil and obliterate the channel unless a way were found to hold the earth in place. The answer was simple and natural—a well-maintained grass cover to anchor the soil.

Creating a grassy, open area in the midst of a rapidly growing urban area with rising real estate values, however, is an invitation to development—development that would reduce the area's flood control ability. So planners found a use for the area that will help stave off pressure for

Development for recreation should help Indian Bend Wash resist pressures for commercial and residential construction.

construction and is compatible with flood control: the greenbelt is being developed for recreational uses. Parks and golf courses have been built, facilities for sports and picnicking installed, and a bicycle trail will run its length. An exhibit plaza will serve dual purposes; while providing facilities for cultural events, it will protect a downstream bridge from flood waters by means of its concrete base. A six-acre lake at the lower end of the greenbelt will be stocked with fish. It also will help still flood waters, collect them, and guide them into the channel through Tempe. All the permanent structures in the area are being built above the high water mark of the hypothetical 100-year flood that the Indian Bend Wash project is designed to contain. Other facilities are intended to withstand flooding.

The greenbelt plan won the support of area residents even though the local share of the costs is higher than it would have been under the original plan. The Federal government is paying for most of the conventional contruction—the lake, the exhibit plaza, two park areas, and an interceptor channel along the Arizona Canal, which runs across the upstream end of the project area. Local entities are paying for the rest of the project. The Maricopa County Flood Control District is funding utility relocations and providing real estate required for the construction aspects of the project. The city of Scottsdale has supplied the real estate within the greenbelt and is moving utilities and rebuilding bridges. In addition, the city is paying for half the costs of recreation facilities built as part of the federal aspects of the project. The Corps plans to finish construction in September 1980.

Indian Bend Wash has won recognition for the way careful project design provides both flood control and recreation in a manner sensitive to environmental and social values. The National Society of Professional Engineers ranked Indian Bend Wash among the ten outstanding engineering achievements of 1974. In addition, the project has received the endorsements of a host of Federal and state environmental agencies and the compliments of two environmental organizations, the Sierra Club and Friends of the Earth. ■

Historic Birth in Oklahoma

by **Curtis Weddle**

A Bald Eagle has hatched in Oklahoma. If available information is correct, this is the first such birth in the state since 1849, and it has excited ornithologists, naturalists and just plain "bird watchers."

Corps of Engineer Rangers at Robert S. Kerr Lake, a key unit of the McClellan-Kerr Arkansas River Navigation System, had been enthusiastic about a new eagle nest discovered early this year on the Sans Bois Creek arm of the lake. The nest, within sight and sound of a busy coal loading port, was in the same general area as one found and observed during the spring of 1976. Definitely "brooded" by a pair of bald eagles, the 1976 nest collapsed during a heavy rainstorm in early May and was abandoned by its occupants. Additional eagle sightings were made in the area in 1977; however, it was not until the 1978 season that new nesting activity and probable brooding by a pair of eagles was observed.

As spring advanced, rangers continued their vigil and issued guarded, but optimistic, reports. Even though the nest was in a busy, easily visible and accessible location—tows and barges were using the coal loading port on a regular basis—there was additional concern about scaring off the adult eagles with too many outside observers. A single helicopter overflight of the nesting site, at a discreet and nondisturbing distance and altitude, revealed nothing except the adult eagles.

In May a boat and crew were dispatched for close range observation and telephoto photography. Not only had an eagle been hatched, it was almost as big as its remaining parent! One of the adults, apparently the male, had not been seen for some time and was probably on an extended hunting foray. Experts told rangers this is often the case when young are being raised.

A full month prior to presstime, the eaglet was seen standing at the edge of the nest in preparation for his first flight.

Kerr Lake officials are hopeful that the successful birth will herald the return of numbers of nesting eagles to

The immature eaglet, right, prepares for his first flight.

Oklahoma, and are already looking into the possibility of constructing nesting "trees" for the time when the standing timber on the Sans Bois Creek is no longer available. ■

U.S. Waterborne Commerce Sets Record

Commerce on U.S. waterways reached an estimated 1,900,600,000 tons in 1977, some 3.6 percent higher than the previous year and a new annual record. Foreign commerce increased by 6.9 percent over 1976 and accounted for 48 percent of tonnage carried on U.S. waterways. Approximately two-thirds of the foreign commerce was imports, an increase of 11.3 percent over the preceding year. Exports declined by two percent from 1976. Of domestic commerce, the largest increase—3.7 percent over the preceding year—occurred in transport between U.S. ports on the Great Lakes. Along the coasts domestic tonnage rose less than one percent. Inland domestic tonnage fell by a similar proportion. Inland commerce accounts for about two-thirds of domestic tonnage, coastal transportation for about one quarter, and Great Lakes, the remainder. ■

Engineers on Camels?

That was what frontiersmen on the Texas plains saw in 1859 when an exploring party led by Lt. William H. Echols of the Corps of Topographical Engineers set out from Camp Hudson on the Devil's River. Suggested by former Secretary of War Jefferson Davis, the beasts were supposed to simplify exploration of the American desert. But the camel drivers knew so little about handling them that the packs piled on their humps kept falling to the ground.

The tale of engineers on camels comes from Lynn Alperin's *Custodians of the Coast: The History of the United States Army Engineers at Galveston,* one of nearly 30 histories of U.S. Army Corps of Engineers districts, divisions, and laboratories published under the Corps' field operating agency historical program. At first voluntary, the program began in 1966. Since then the histories have become more sophisticated and scholarly, and in 1976 Chief of Engineers Lt. Gen. John W. Morris made the program mandatory. Each of the field operating agencies, rather than a central office, supervises the preparation of its history. Recent reports that have received wide praise are histories of the Galveston, Huntington, and Memphis districts. Accounts of the Baltimore, St. Louis, and Buffalo districts and the New England Division are being published this year.

Copies of histories can be purchased from the issuing field operating agencies. Information on the historical program is available from the Historical Division, Office of the Chief of Engineers, P.O. Box 1715, Baltimore, MD 21203. ■

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Coming Events

Southeast Fish and Wildlife Conference at Hot Springs, Va., November 5-8, 1978.

31st Annual Gulf and Caribbean Fisheries Institute at Quintana Roo, Mex., November 5-10, 1978.

14th American Water Resources Conference at Orlando, Fla., November 6-10, 1978.

National Symposium on Wetlands at Orlando, Fla., November 7-10, 1978.

Administrative Management Program for Natural Resource Managers at Pennsylvania State University, University Park, Pa., December 3-15, 1978.

National Shooting, Hunting, Outdoor Trade Show at St. Louis, Mo., January 9-11, 1979.

3rd Nongame Bird Habitat Management Workshop at Minneapolis, Minn., January 23-25, 1979. ■

Bookshelf

Western Water magazine explores a broad range of water topics. Most articles focus on California topics, but the issues they discuss have national—and even international—implications. The journal is published bimonthly by the Western Water Education Foundation, a non-partisan public information organization founded in 1977 by the Association of California Water Agencies. For information about subscriptions and the Foundation, write: Western Water Education Foundation, 1107 Ninth St., Suite 618, Sacramento, CA 95814. ■

Fisheries, a bimonthly aquatic resource magazine, is published by the American Fisheries Society, an international organization of aquatic science professional, lay, and student members. Chartered in 1870, AFS is the world's oldest and largest scientific group dedicated to the advancement of fisheries science and the conservation of renewable aquatic resources. The magazine features articles on aquaculture, conservation and the environment, energy, exotic and endangered species, fish culture and fish health, fisheries management, and water quality. In addition, it contains announcements of interest to fisheries people, reports on fisheries developments, equipment and materials advertisements, a schedule of fisheries meetings, and news and photos of AFS activities. Subscriptions are available from AFS, 5410 Grosvenor Lane, Bethesda, MD 20014. ■

Paying for Pollution: Water Quality and Effluent Charges asks whether current law requiring use of "best available technology" for water pollution control should be replaced or supplemented by a system of effluent charges—fees for the discharge of pollutants. Effluent charges are intended to make polluting uneconomical and to motivate continuing improvements in control technology. Among those offering contrasting opinions in these proceedings of a May 1977 conference are the current and two past administrators of the U.S. Environmental Protection Agency. Available from the Conservation Foundation, 1717 Massachusetts Ave., NW, Washington, DC 20036. ■

Interactions Between Sediments and Fresh Water, edited by H. L. Golterman, presents papers from the 32-nation international conference of the same name held in 1976 at the Hague, Netherlands. Chapter headings include: Sources and Composition of Sediment; Sediment Formation and Rate of Sediment; Role of Sediments in Element Cycles; and Water Quality, Health and Management Aspects of Sediments. Dr. W. Junk B. V. Publishers, The Hague and Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands. ■

Changes of Command

Major General Bates C. Burnell is the new Deputy Chief of Engineers in Washington, D.C. General Burnell served as Director of Military Construction from August 1975 to January 1978. Most recently, he was Assistant Deputy Chief of Staff for Logistics, Department of the Army. He succeeds Lieutenant General Ernest Graves, Jr., who has become Director of the Defense Security Assistance Agency.

Brigadier General Hugh G. Robinson has become Deputy Director of Civil Works in the Office of the Chief of Engineers (OCE), Washington, D.C. General Robinson, who received his star June 30, comes to Washington from California, where he had been serving as Los Angeles District Engineer. General Robinson previously served as Commander of the U.S. Army Engineer School Brigade at Fort Belvoir, Virginia, and, from 1965 to 1969, as Army Aide to President Lyndon Johnson. General Robinson replaces Brigadier General Drake Wilson, who has been assigned as European Division Engineer in Frankfurt, Germany.

Brigadier General Richard M. Wells has become Division Engineer, North Pacific Division, succeeding Major General Wesley E. Peel, who becomes Commanding General of Fort Leonard Wood, Missouri. General Wells was Division Engineer, Middle East Division, Riyadh, Saudi Arabia.

Brigadier General Norman G. Delbridge has been assigned as South Pacific Division Engineer at San Francisco, California. He succeeds Colonel William E. Vandenberg, who has been acting division engineer since January. General Delbridge was serving as the European Division Engineer in Frankfurt, Germany.

Colonel Tilford C. Creel has replaced Colonel Francis J. Walter, Jr., as Savannah District Engineer. Colonel Walter has become Special Assistant to the Chief of Engineers, Washington, D.C. Colonel Creel was Assistant Director of Civil Works, Upper Mississippi Basin and Great Lakes, OCE. ■

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